

Recent and future research programs

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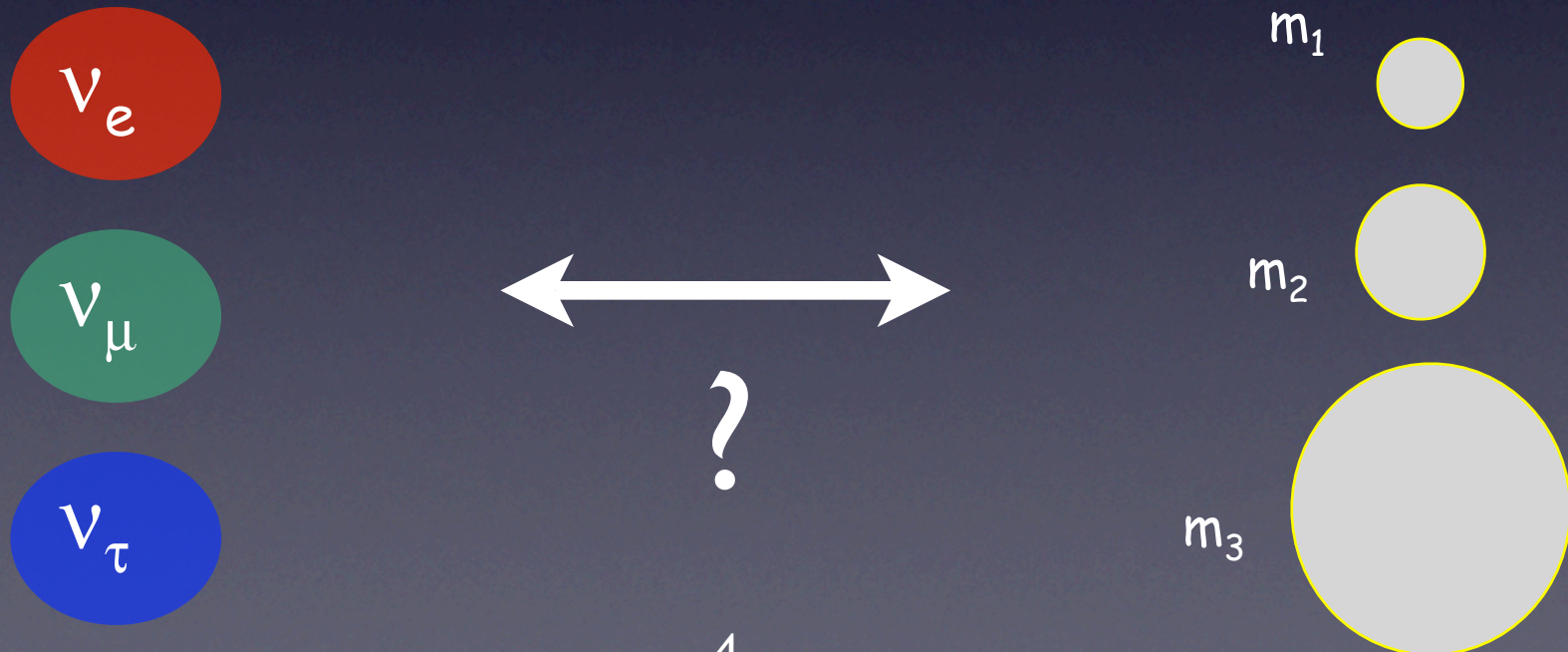
Outline

- Introduction
- K2K experiment and SciBar detector
- Results from K2K/SciBar
- Research plans

Present research:
Long-baseline neutrino
oscillation experiments

Flavor mixing

- If flavor eigenstate \neq mass eigenstate, Flavors “mix” and transition from one state to another happens after time evolution.
- Mixing of three generations represented by 3x3 unitary matrix (CKM for quarks, MNS for neutrinos)



Neutrino Oscillation

- Oscillation probability of neutrino flavor ν_α to ν_β :
(in two flavor case)

$$P(\nu_\alpha \rightarrow \nu_\beta) = \sin^2 2\theta \times \sin^2 [1.27 \Delta m^2 (L/E)]$$

θ : Mixing angle between two states

Δm^2 : mass-squared difference (in eV^2)

L: flight distance (km)

E: neutrino energy (GeV)

Long Baseline Experiments

- Use accelerator-produced neutrinos

- ✦ Known L , controlled E

$$P(\nu_\alpha \rightarrow \nu_\beta) = \sin^2 2\theta \times \sin^2[1.27 \Delta m^2 (L/E)]$$

- ✦ $\Delta m^2 \sim 3 \times 10^{-3} \text{eV}^2$ (atm. region),

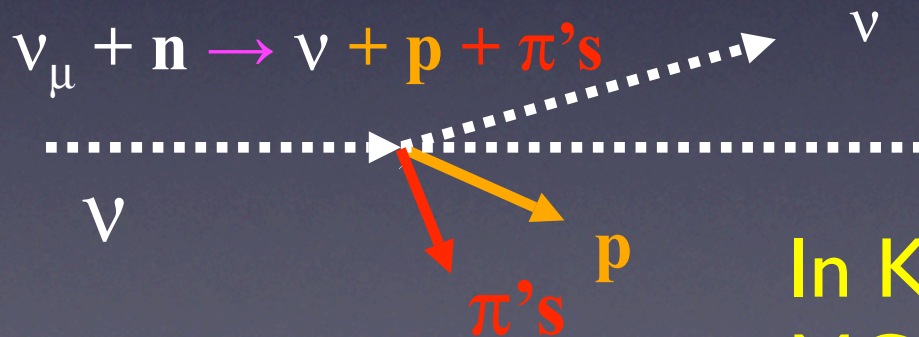
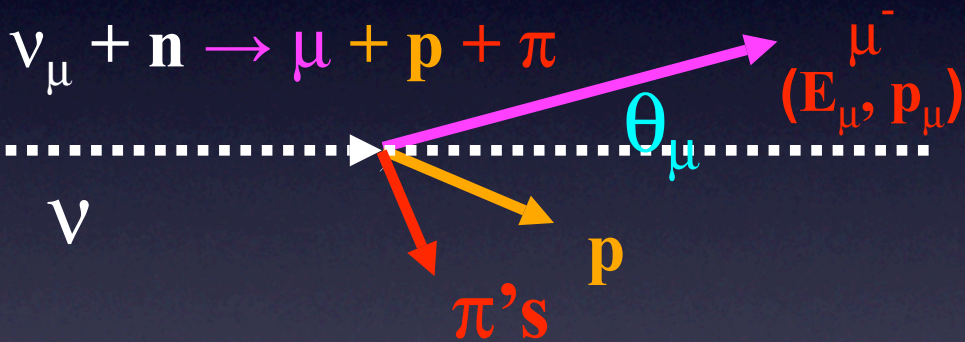
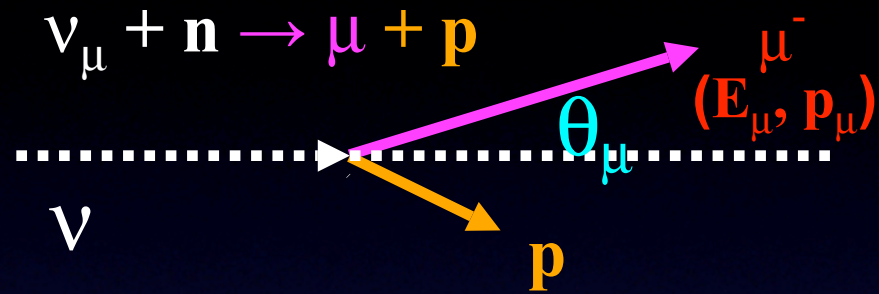
- $L \sim 300\text{-}1000 \text{km} \rightarrow E \sim 1 \text{GeV}$

- Massive *Far* detector for statistics,
Near detector for normalization and
background/interaction study

Detection of ~ 1 GeV neutrino

- Neutrino: lepton with no charge
 - ✦ Only weak interaction is relevant....
- But, the target is usually nucleus!
 - ✦ This complicates the situation very much
 - ✦ Nuclear structure, hadronic interaction, ...
etc. need to be taken into account

Neutrino Interaction @~1 GeV

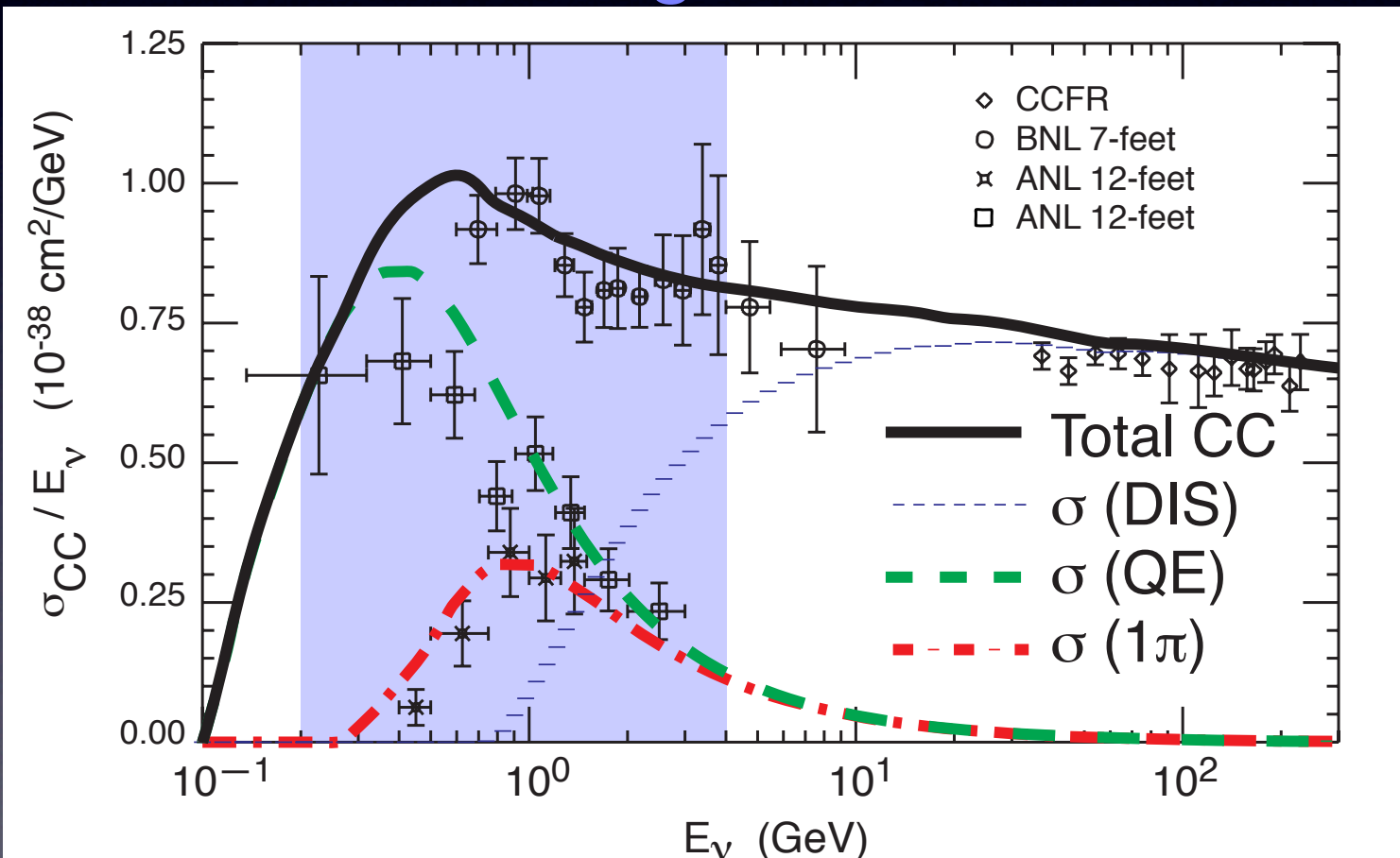


- CC quasi-elastic (QE)
 - ✦ Two body kinematics
 - ✦ can reconstruct E_ν from (θ_μ, p_μ)
- CC non-QE (single-pi, multi-pi, **coherent**, DIS)
 - ✦ Bkg. for E_ν measurement
- NC

In K2K, simulated with “NEUT”
MC library developed at (Super-)K

Current knowledge on ν -N interaction in GeV region

Relevant region



*Uncertainty, uncertainty,
uncertainty...*

Uncertainty, uncertainty, uncertainty...

- There are uncertainties everywhere,
which are hard to control

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- ✦ Absolute neutrino flux

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 - ✦ Absolute neutrino-nucleus cross-sections

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(+ detector systematics)

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 - ✦ Use ratios, not absolute: far/near, non-QE/QE, ..

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 - ✦ Use muon from charged current interaction

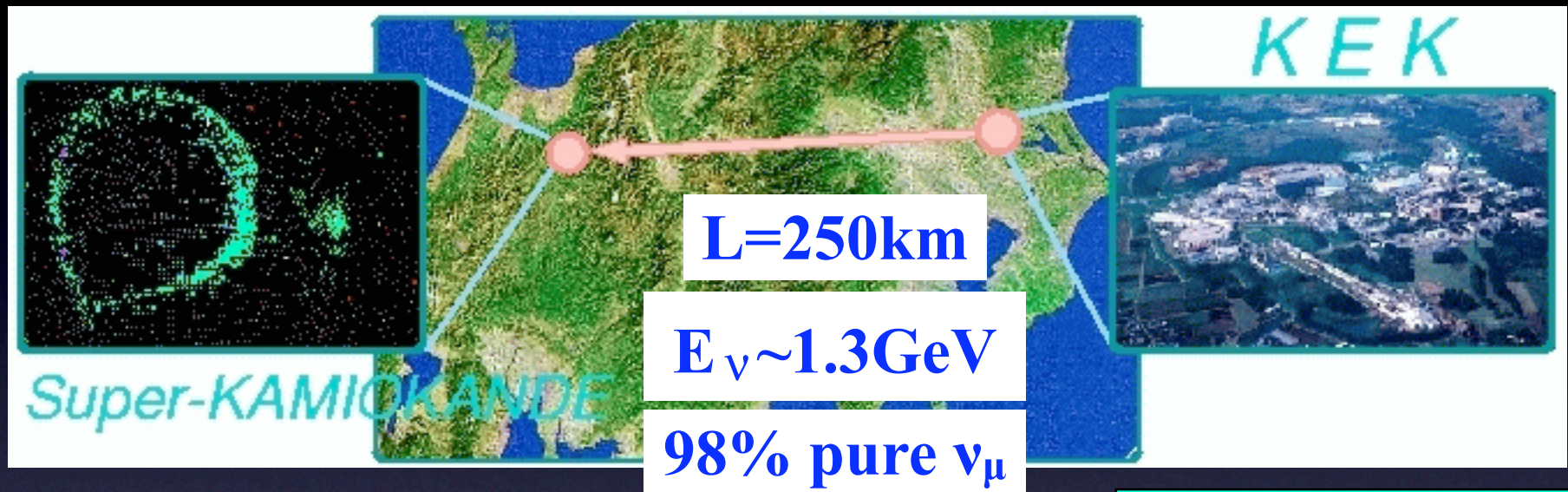
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 - ✦ Absolute neutrino flux
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- Observation is always convolution of these effects!
(+ detector systematics)
 - ✦ Use ratios, not absolute: far/near, non-QE/QE, ..
 - ✦ Use muon from charged current interaction
 - ✦ Study of neutrino-nucleus interaction

K2K experiment

World's first long (>100km) baseline
accelerator experiment

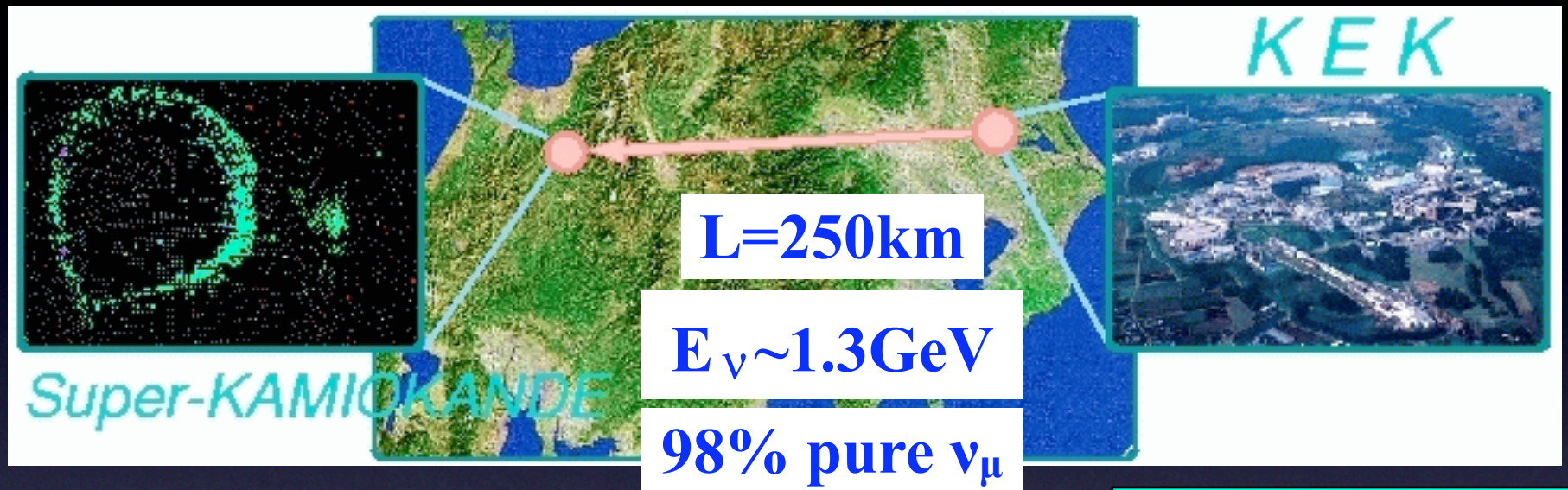
K2K (KEK to Kamioka)



Super-K
(far detector)
50 kton Water
Cherenkov
detector

12GeV
PS@KEK
. ν beam line
. Beam monitor
. Near detectors

K2K (KEK to Kamioka)

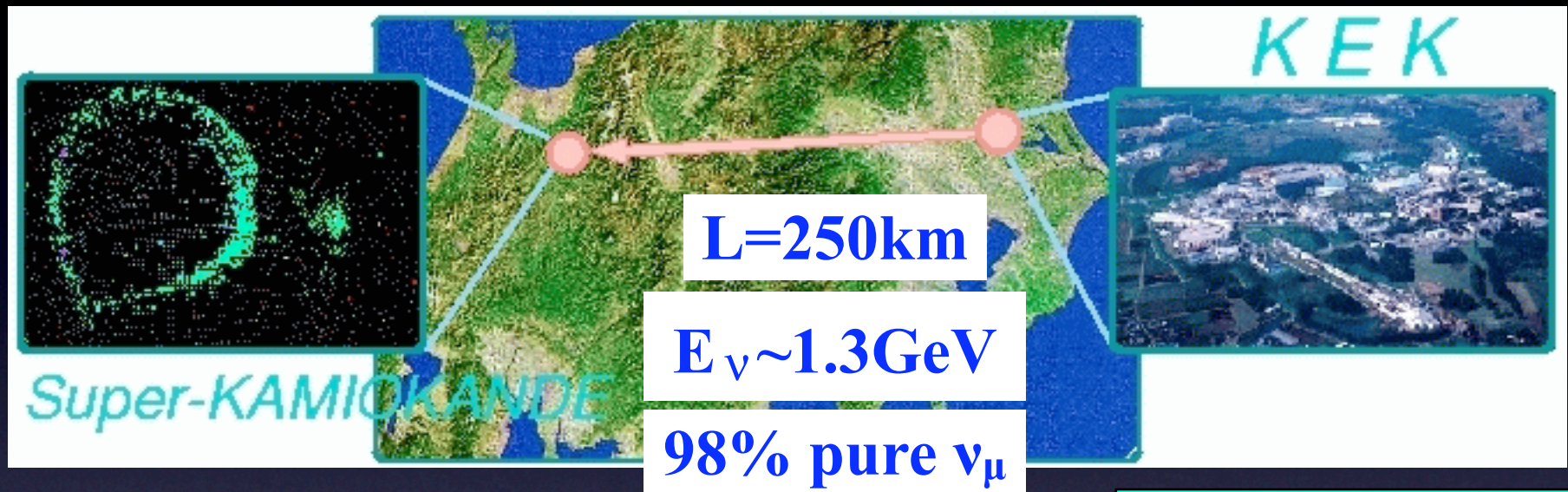


Super-KAMIOKANDE
(far detector)
50 kton water
Cherenkov
detector

Confirmation of ν_μ “disappearance”
observed by Super-K atm. ν

2GeV
@KEK
• ν beam line
• Beam monitor
• Near detectors

K2K (KEK to Kamioka)



Super-KAMIOKANDE (far detector) 50 kton water Cherenkov detector

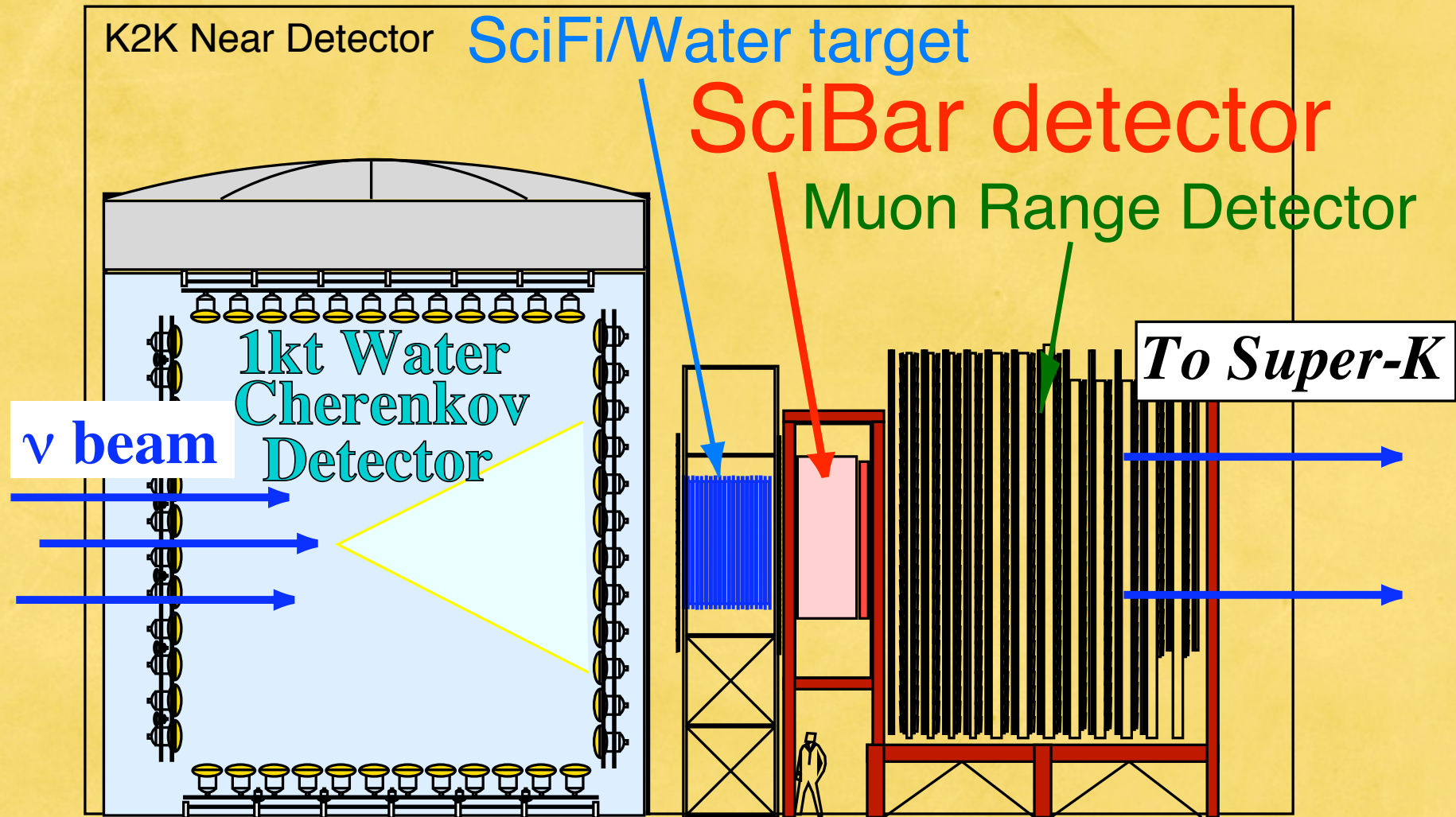
Confirmation of ν_μ "disappearance" observed by Super-K atm. ν

Search for appearance of ν_e from ν_μ beam

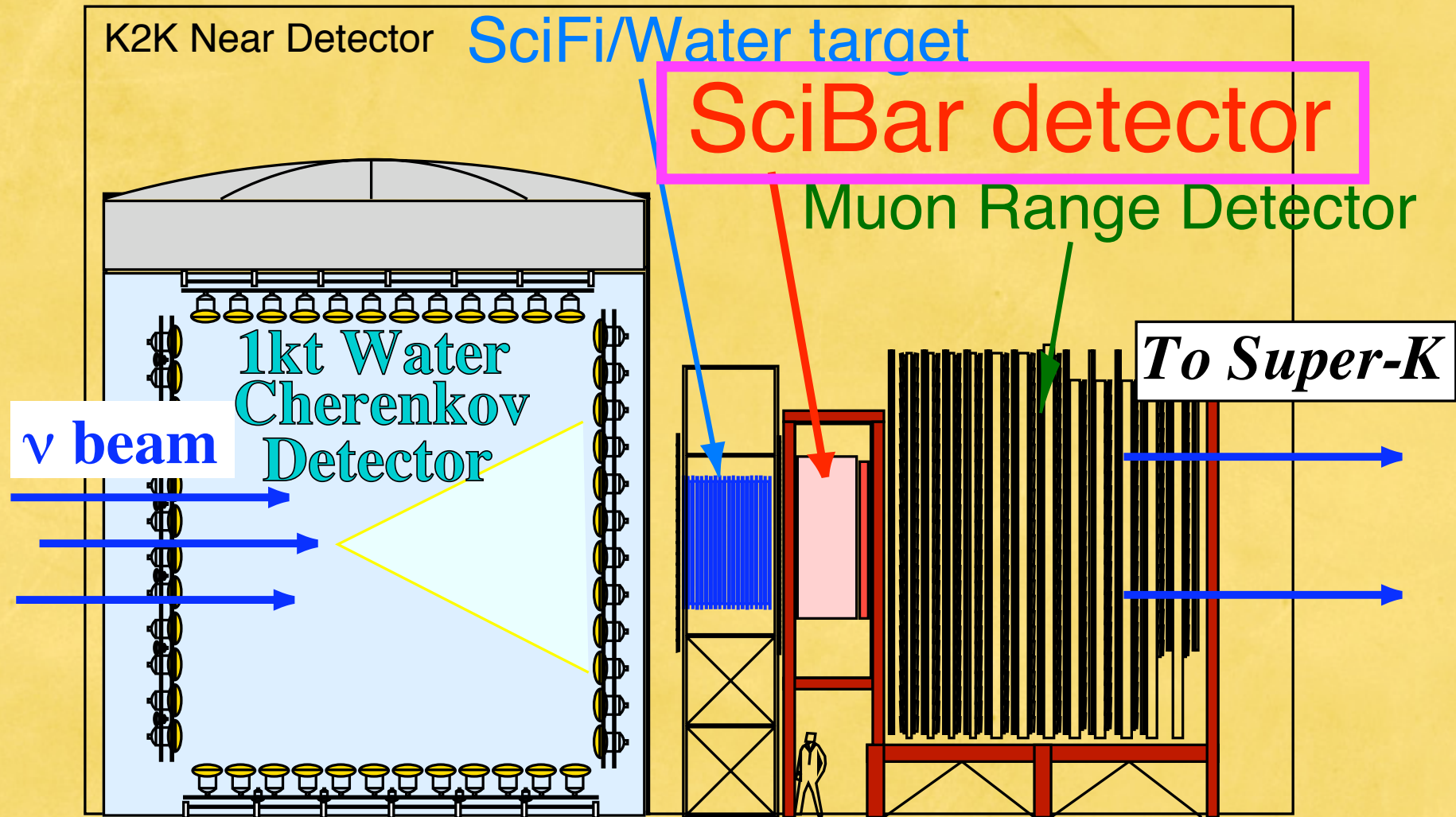
KEK 2GeV ν_μ beam line @KEK

Near detectors

Near Detectors



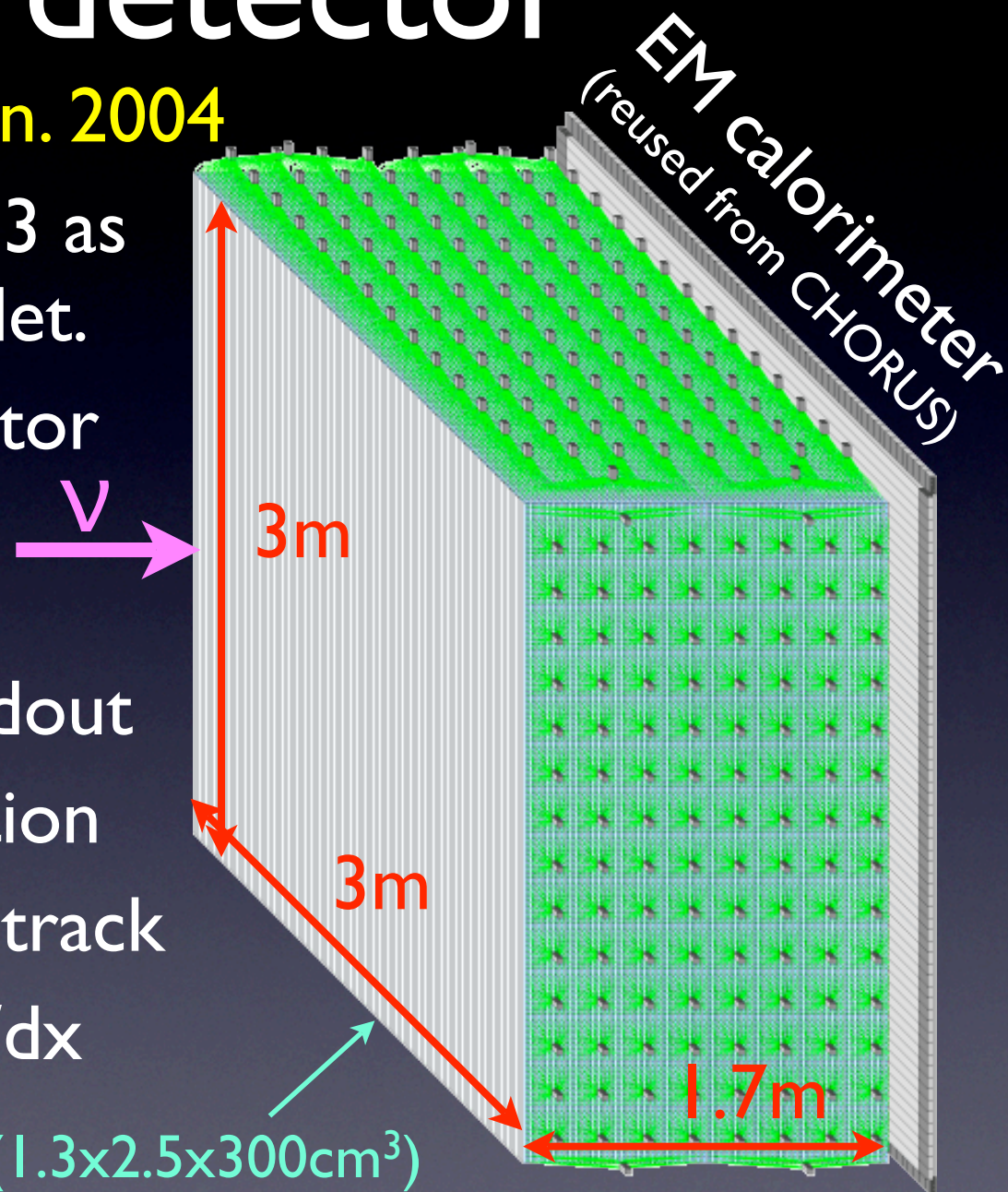
Near Detectors



“SciBar” detector

M.Y. co-convenor since Jan. 2004

- Constructed summer 2003 as an upgrade to K2K near det.
- Fully active tracking detector made of ~15,000
Scintillator Bars
 - ✦ WLS fiber+MAPMT readout
- Study of neutrino interaction
 - ✦ Detect short ($\sim < 10\text{cm}$) track
 - ✦ p/pi separation using dE/dx



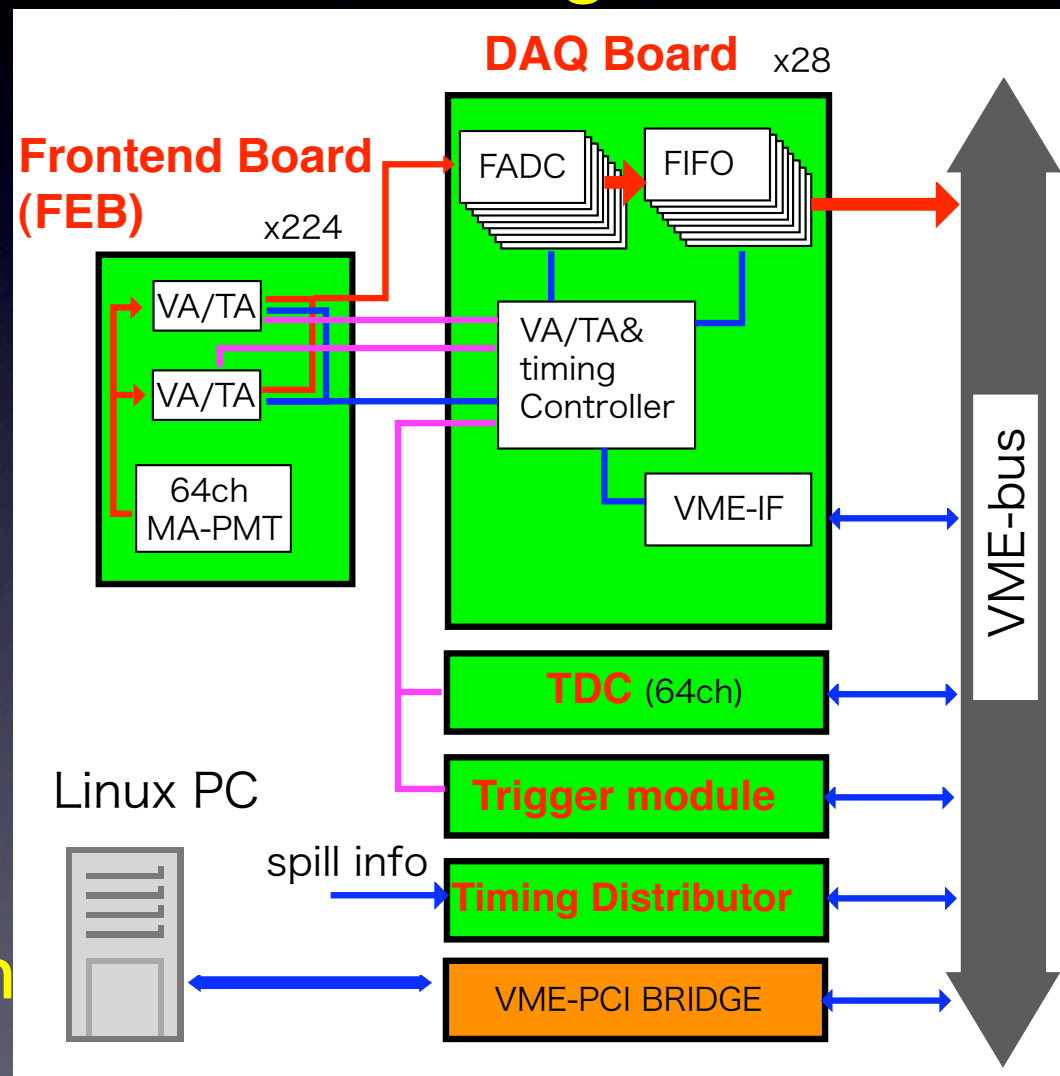
Extruded scintillator ($1.3 \times 2.5 \times 300\text{cm}^3$)

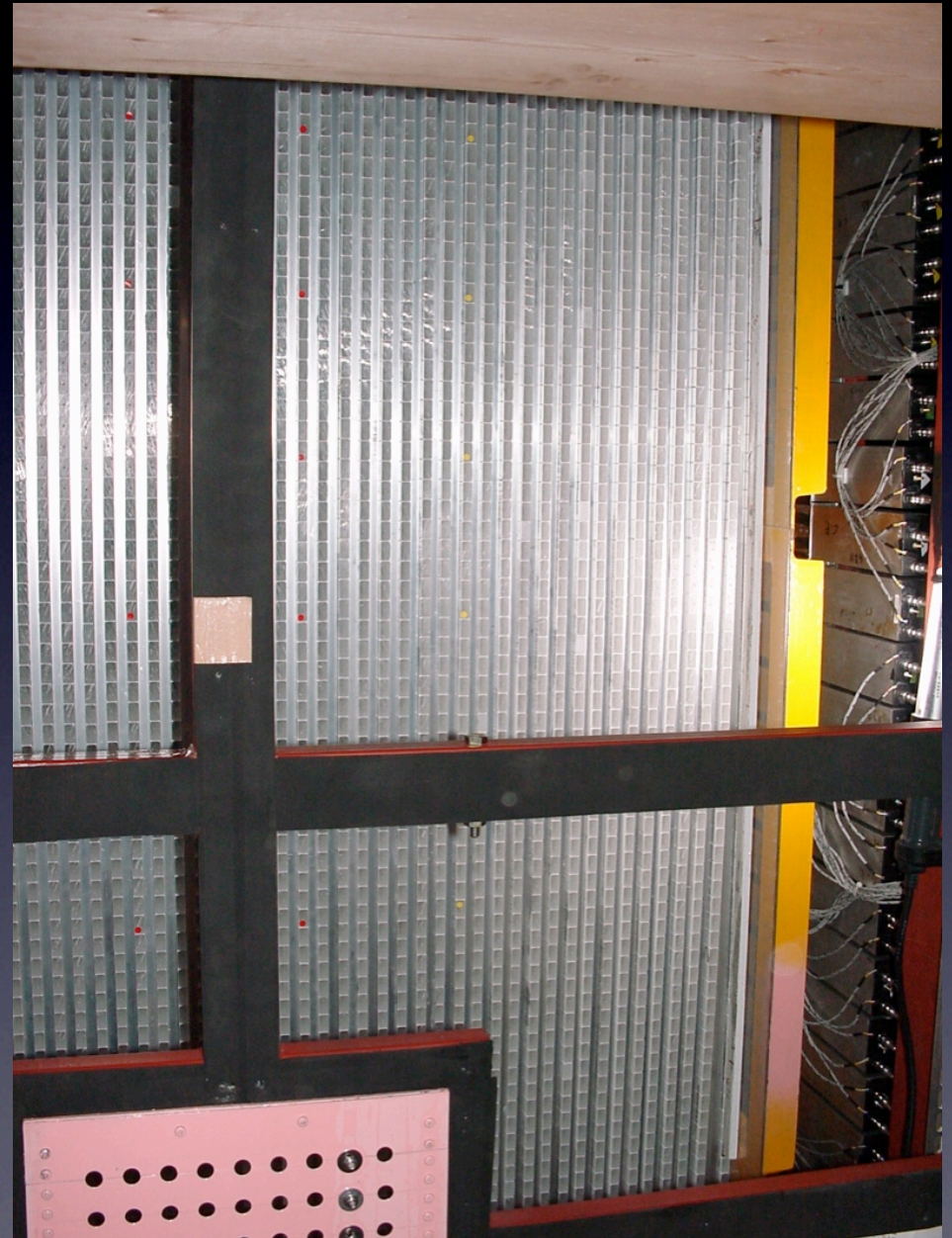
Total weight: 15 tons

SciBar electronics

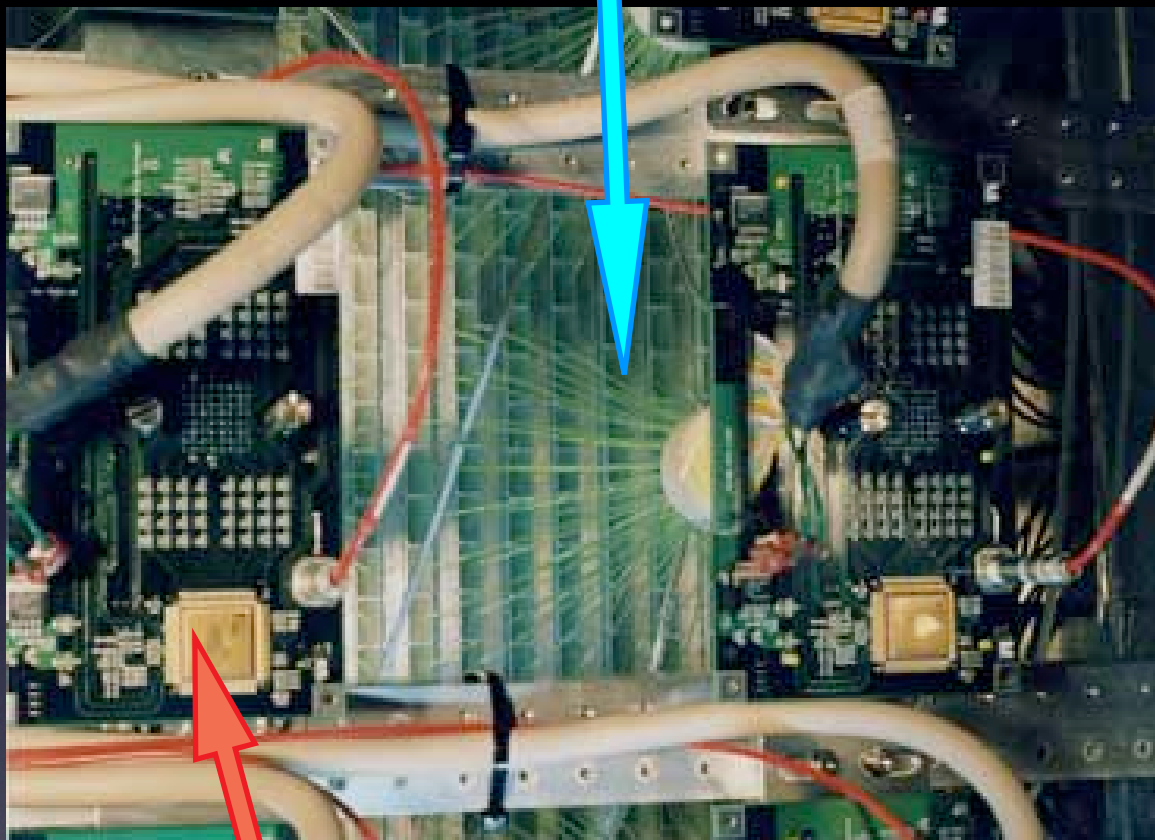
M.Y. project manager
during construction

- Custom electronics developed to handle **~15,000 channels**
- ✦ VA/TA frontend
- Low noise: ~ 0.3 p.e. (MIP=10-20 p.e.)
- Large dynamic range
- ✦ Linear up to ~ 300 p.e.
- Fast trigger/timing signal
- **Successful development in short time (~ 2 years)**



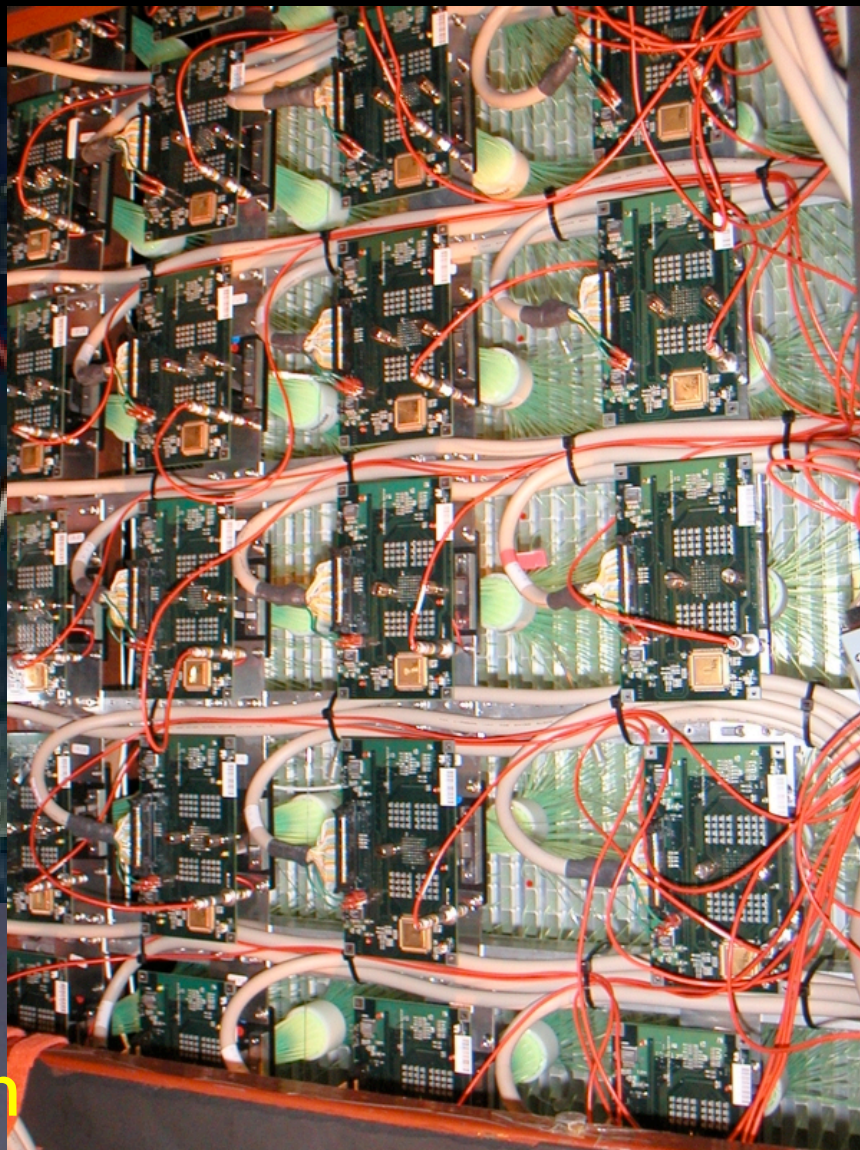


WLS fibers



VA/TA chip

construction/
commissioning in
three months!

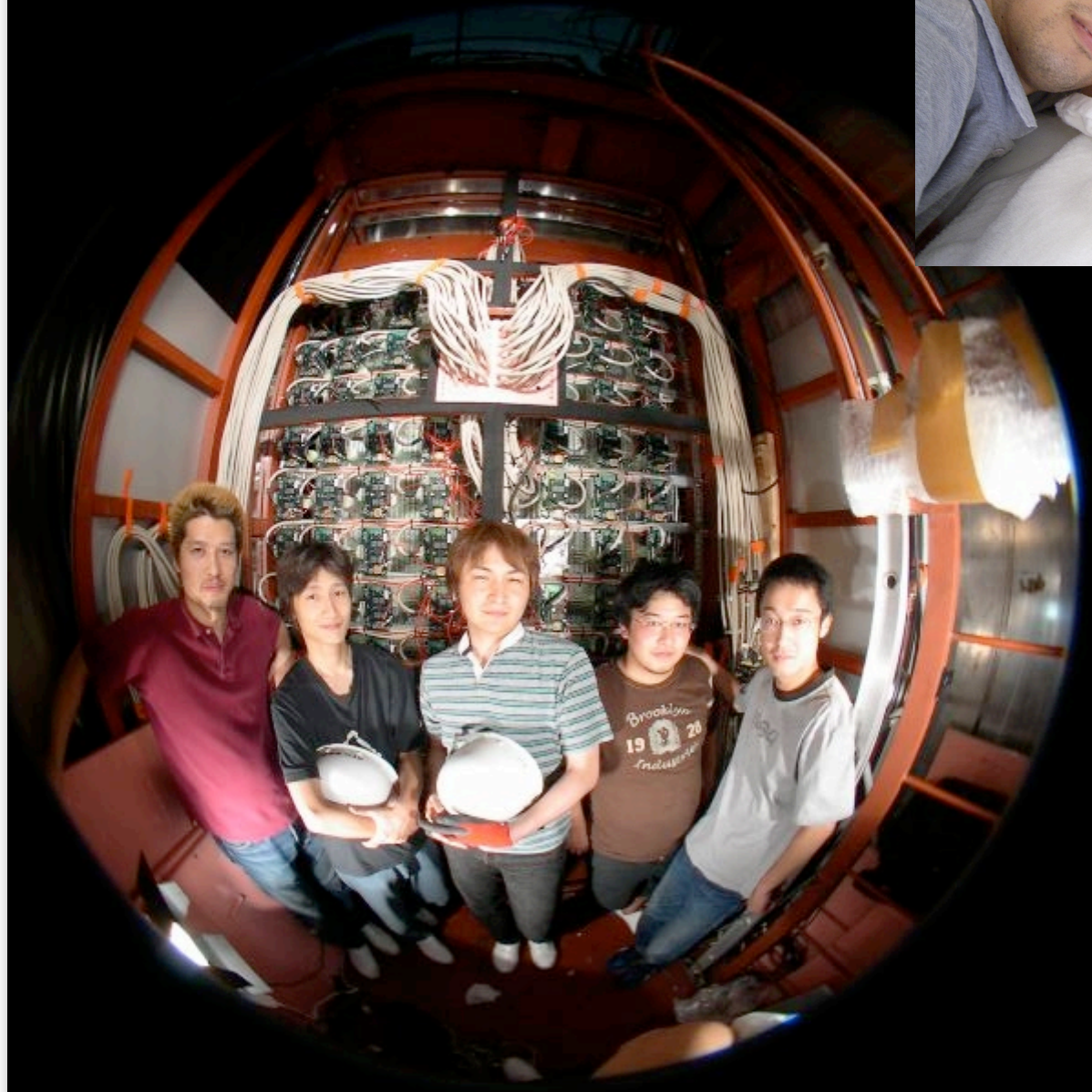


Completed!



Aug. 22, 2003

Completed!

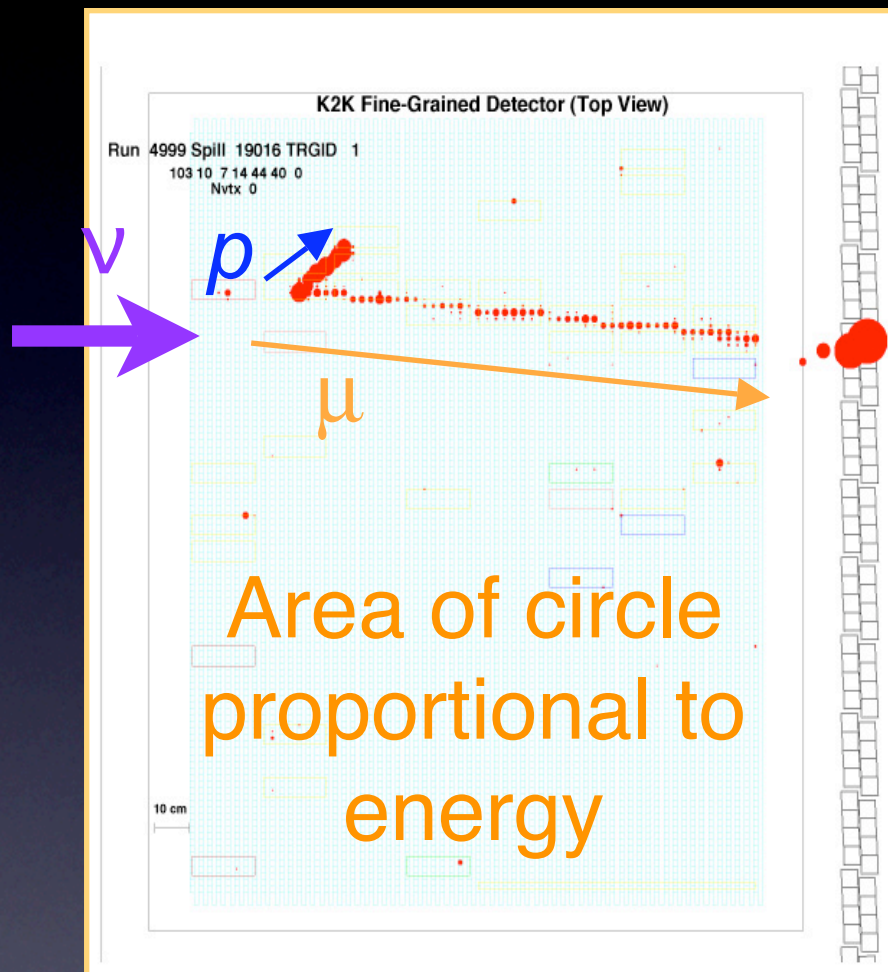


Aug. 22, 2003

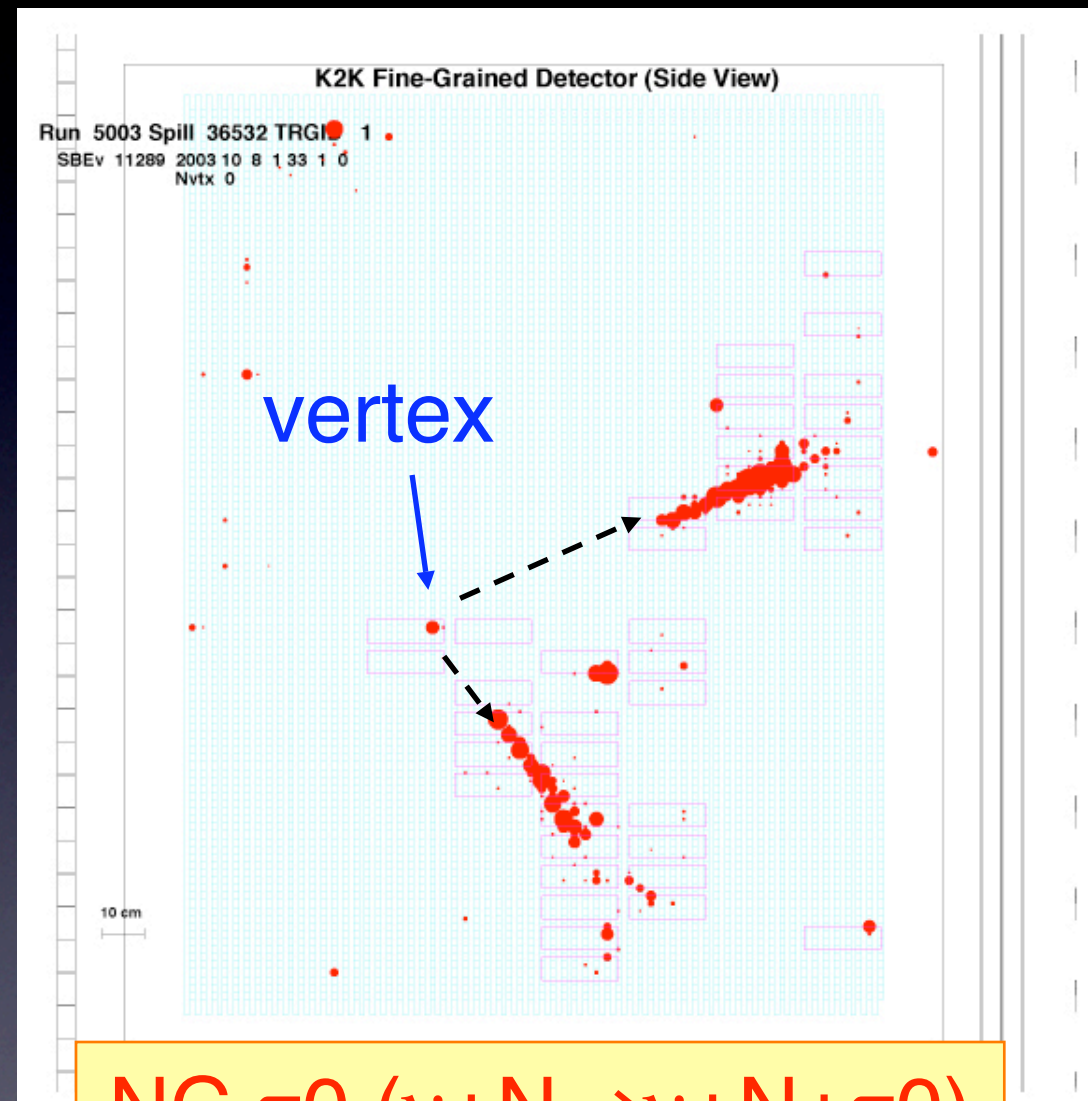


Aug. 26, 2003

Event Displays



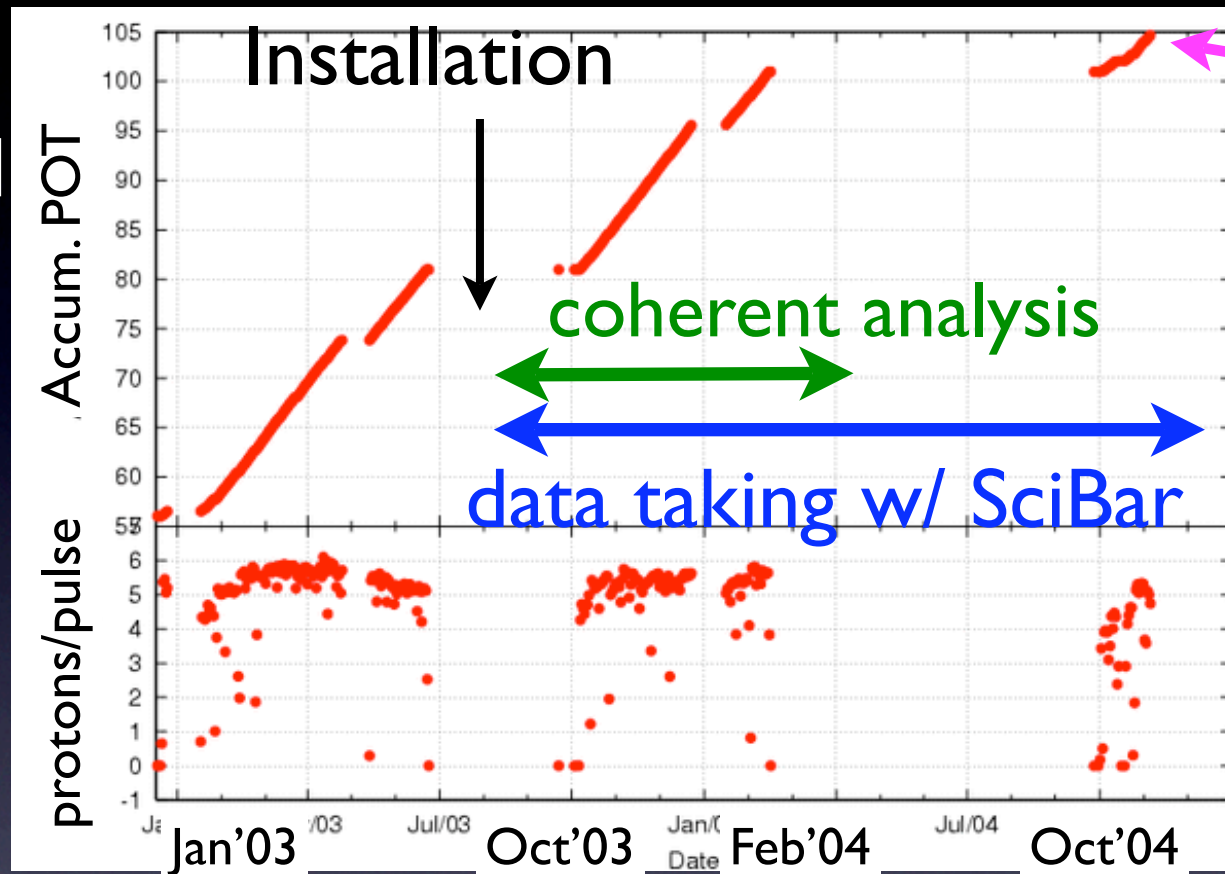
CCQE ($\nu+n \rightarrow \mu^-+p$)
candidate



NC π^0 ($\nu+N \rightarrow \nu+N+\pi^0$)
candidate

Accumulated data

(only period
after SK
recovery
shown)



Completion of
K2K data taking

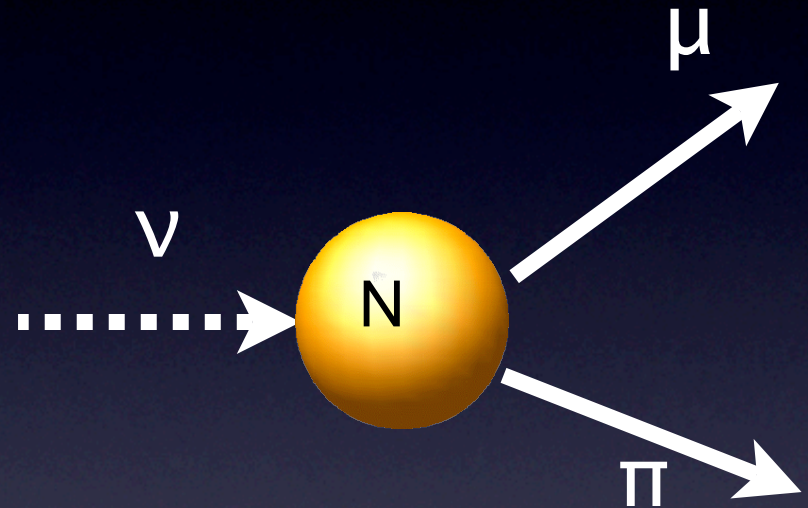
- Stable operation in all period
- 2.1×10^{19} protons on target accumulated (1.9×10^{19} in coherent analysis)
- $\sim 27,000$ neutrino interactions recorded inside ~ 10 ton fiducial volume of SciBar detector

Results from K2K&SciBar detector

- Search for coherent charged pion production
- Final result from ν_μ disappearance analysis

Coherent pion production

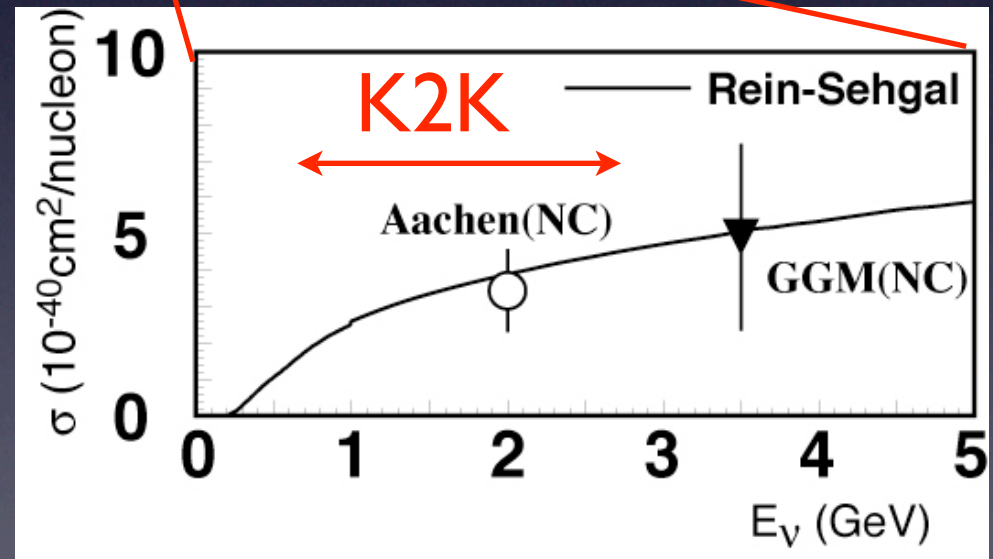
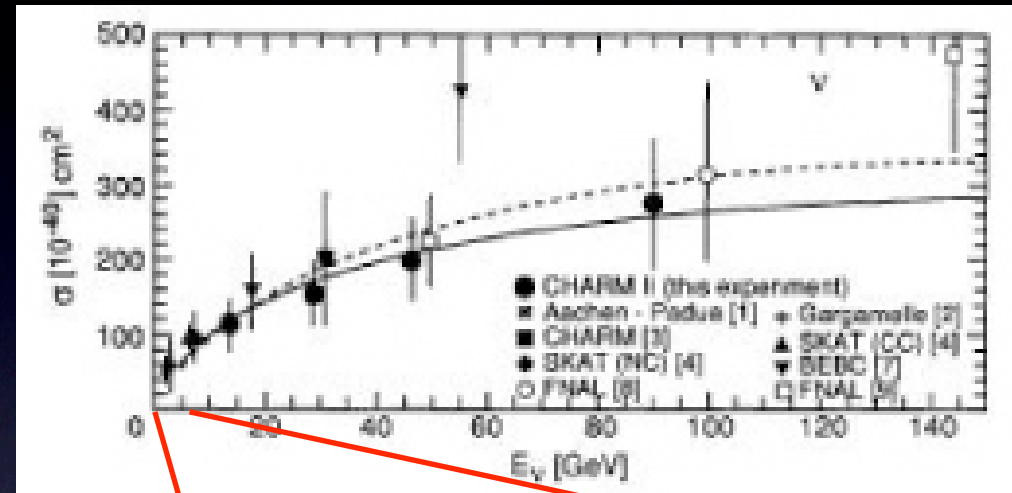
- Neutrino interacts with “entire” nucleus **coherently**
- Small momentum transfer
 - ✦ low q^2
 - ✦ muon & pion go forward direction
- No other particle in the final state
- 2-3% of CC predicted from models at K2K energy
- NC mode is main background for ν_e appearance



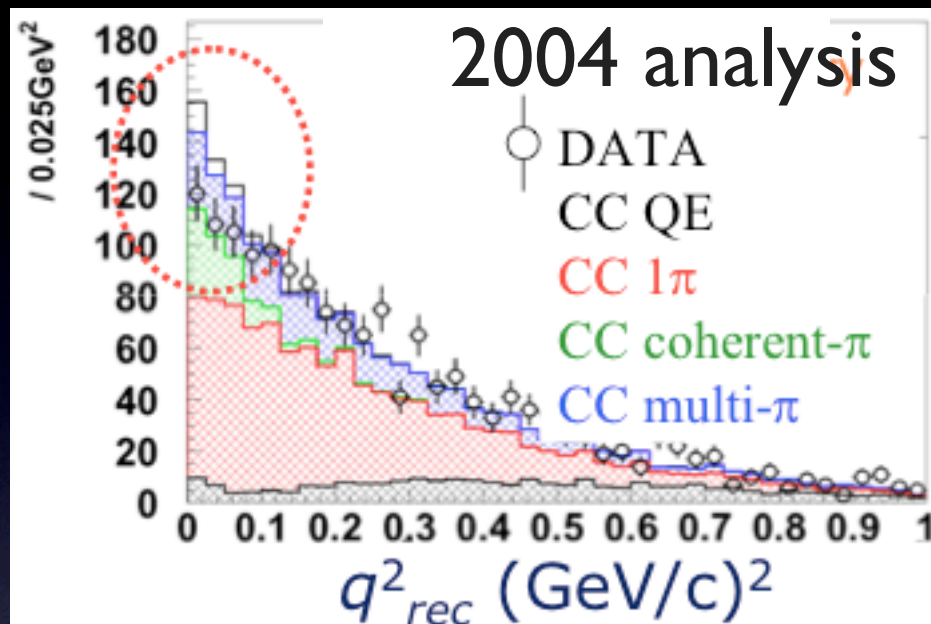
Past Measurements

- **No** measurement for CC in \sim GeV region
- NC measurement at 2 GeV (Aachen-Padova) using Al target
- Theoretical model by **Rein&Sehgal** agrees with past meas (at higher energies).

Rein and Sehgal: Nucl. Phys.
B 223, 29 (1983)



Our Motivation: “low- q^2 puzzle”



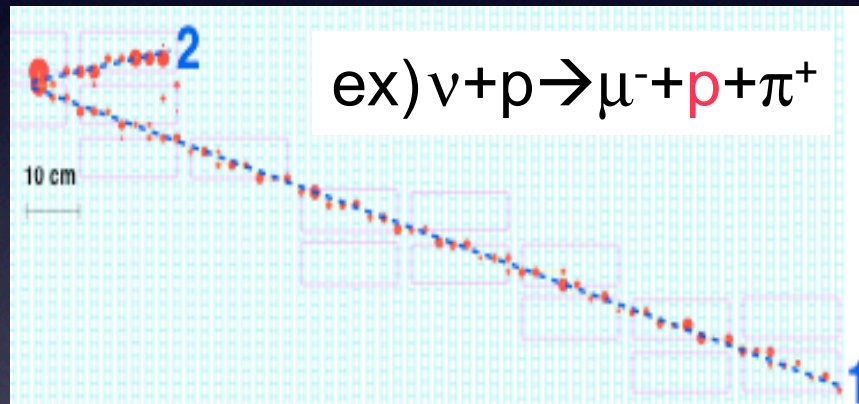
“non-QE” enriched sample

q^2_{rec} : from p_μ/θ_μ , assuming CCQE kinematics

- K2K observed “deficit” in low q^2 region
 - ✦ Limit reliability of interaction model
 - ✦ Coherent pion channel is one of possible sources (vs. resonance pion prod.)
 - ✦ SciBar can discriminate these two thanks to good second track recon. capability (esp. p/ π ID)

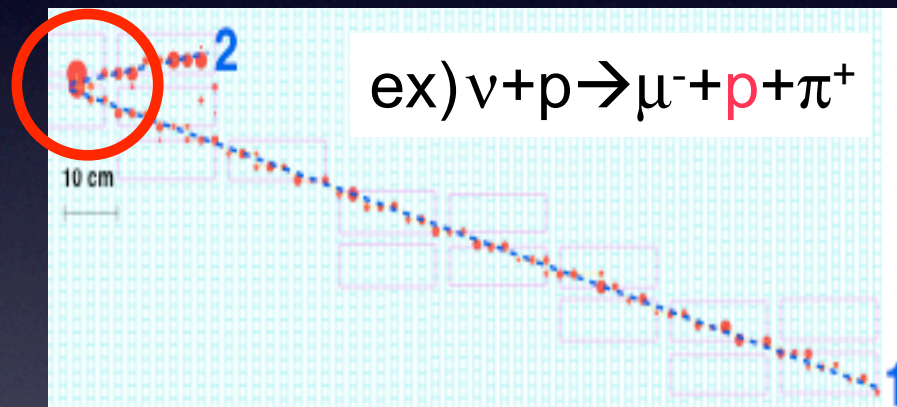
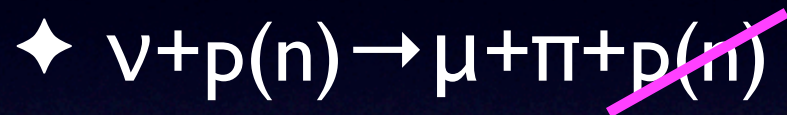
Major background

- CC resonance pion production
 - ✦ $\nu + p(n) \rightarrow \mu + \pi + p(n)$



Major background

- CC resonance pion production

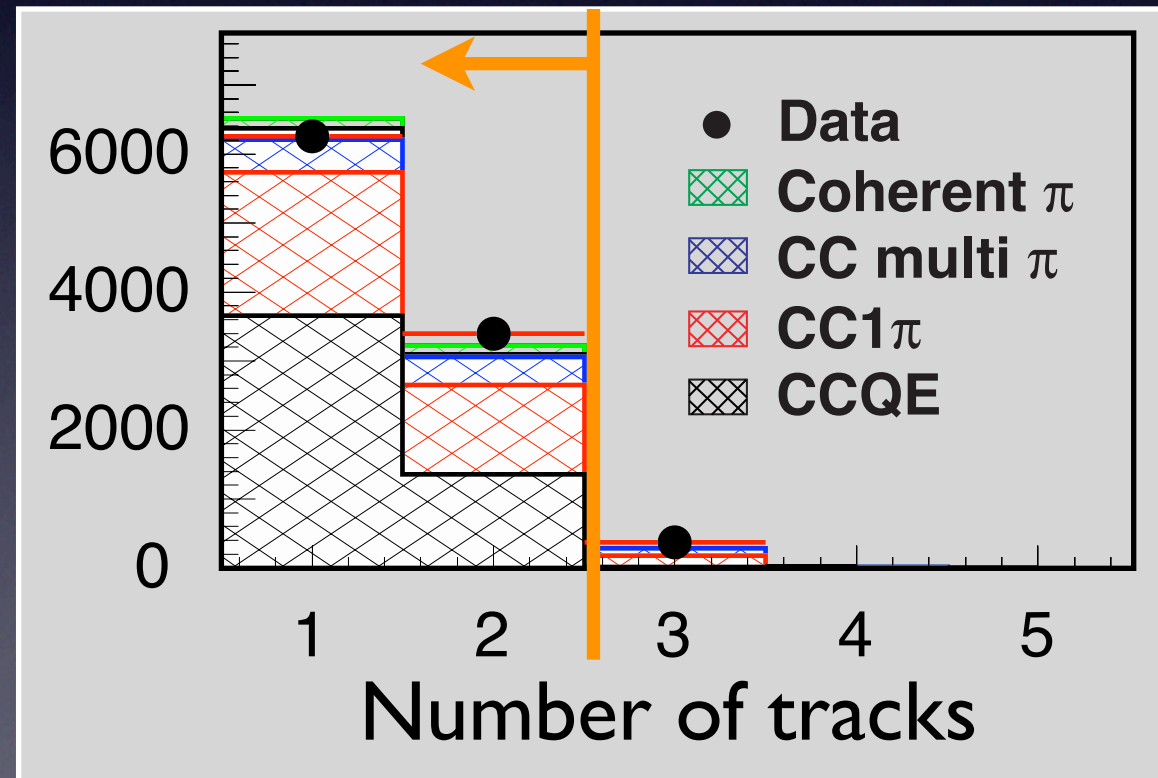
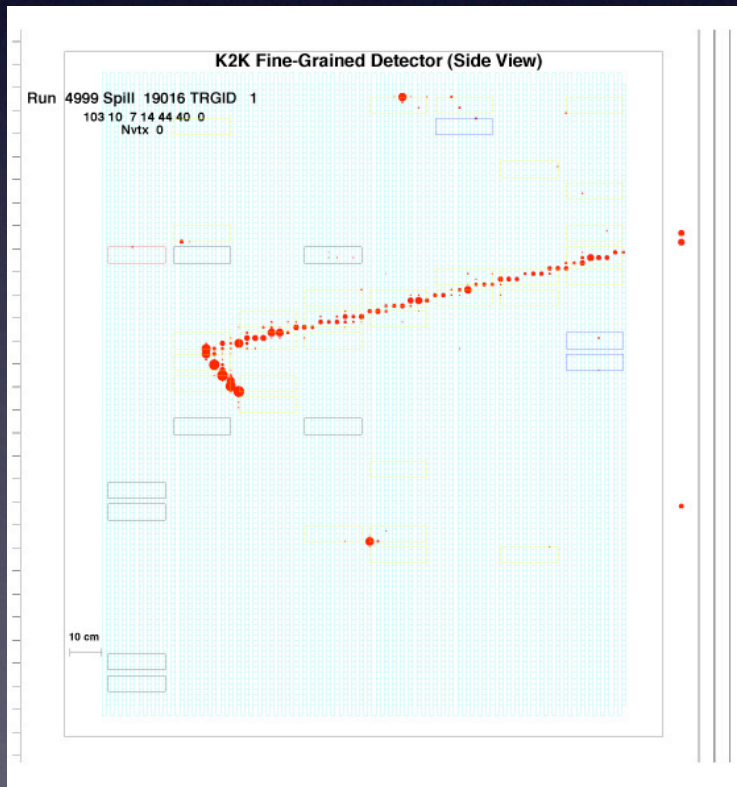


Even if not reconstructed in tracking,
can be detected as energy deposit around the vertex
(Fully active detector!)

Data analysis

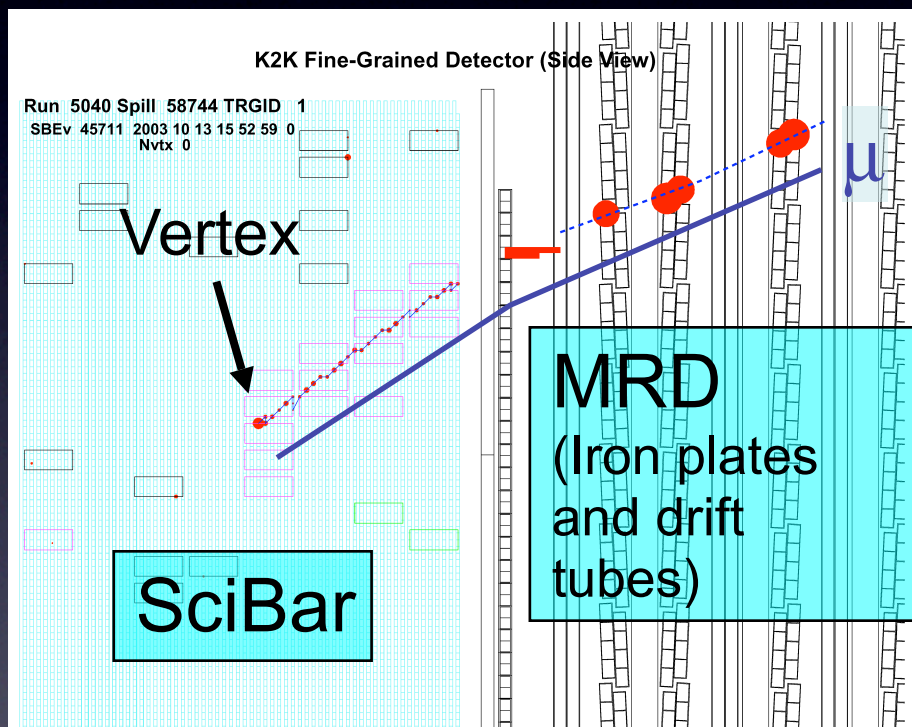
Track reconstruction

- Require ≥ 3 (z-) layer hits
 - ✦ Minimum track length $\sim 8\text{cm}$
 - ✦ Threshold $\sim 450\text{MeV}/c$ for protons

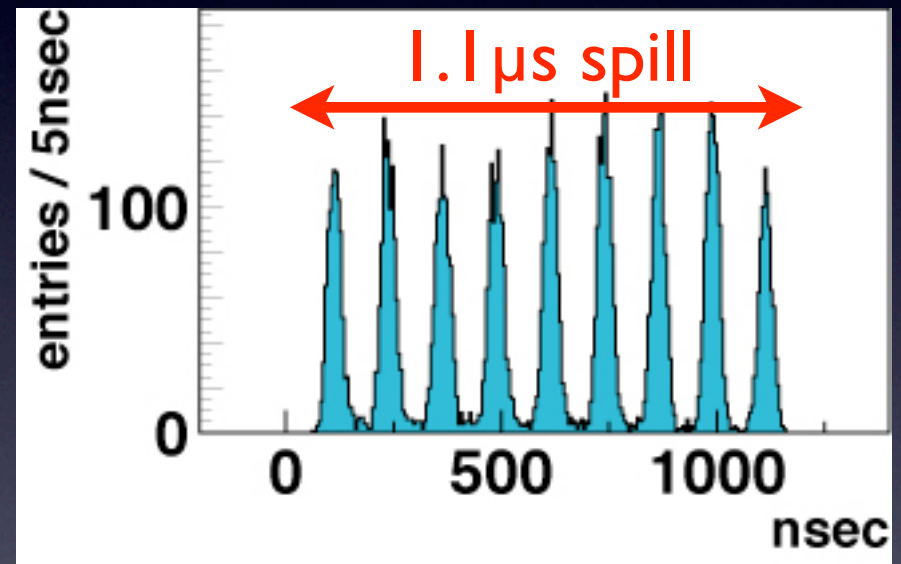


Selecting CC events

- Require matching b/w tracks in SciBar and MRD (Muon Range Detector)



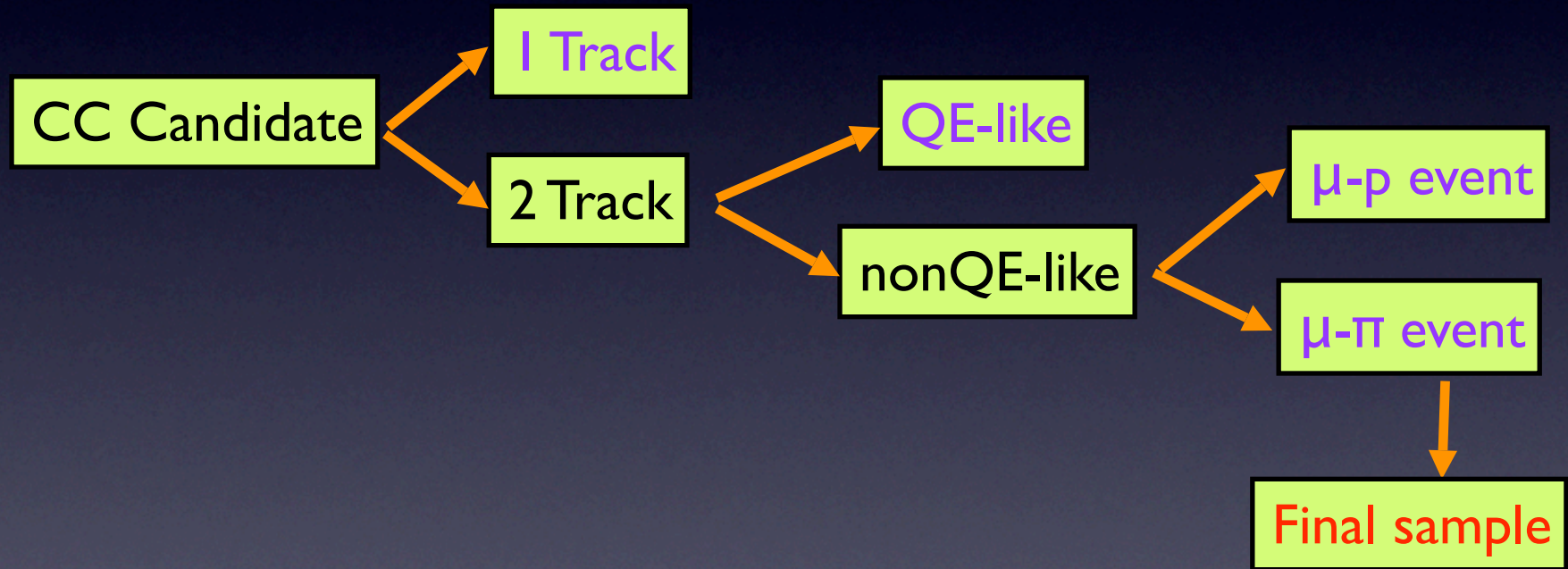
Timing distribution of selected track



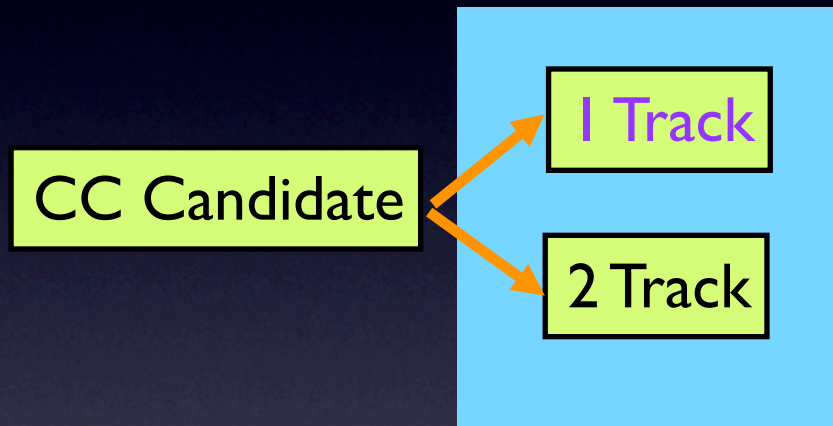
Efficiency for CC: 57% (MC)

~98% CC purity (MC), negligible non-neutrino BG

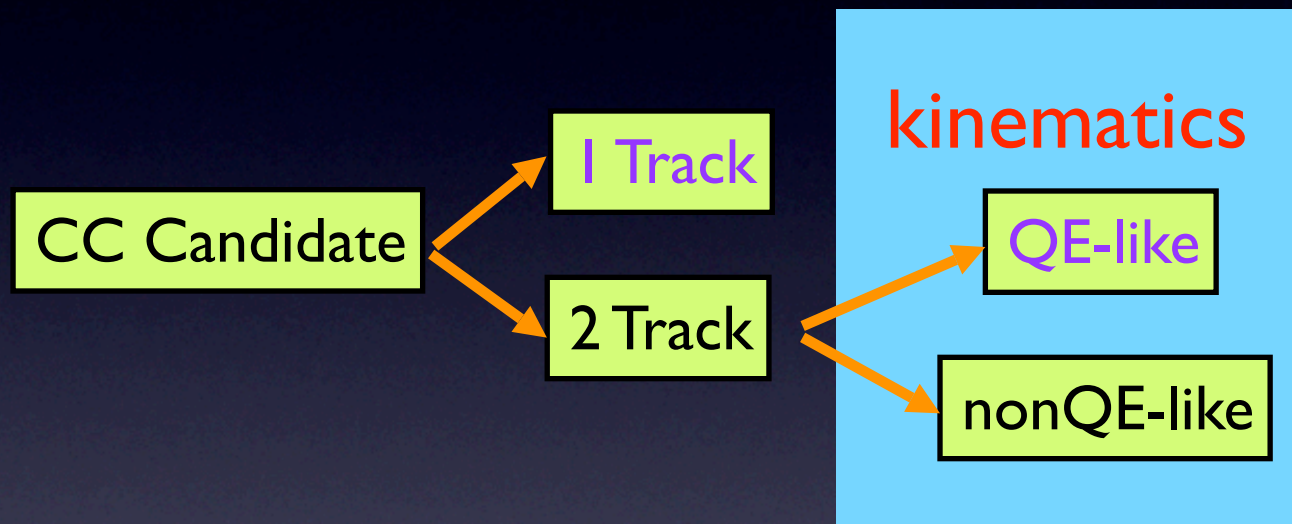
Event Selection



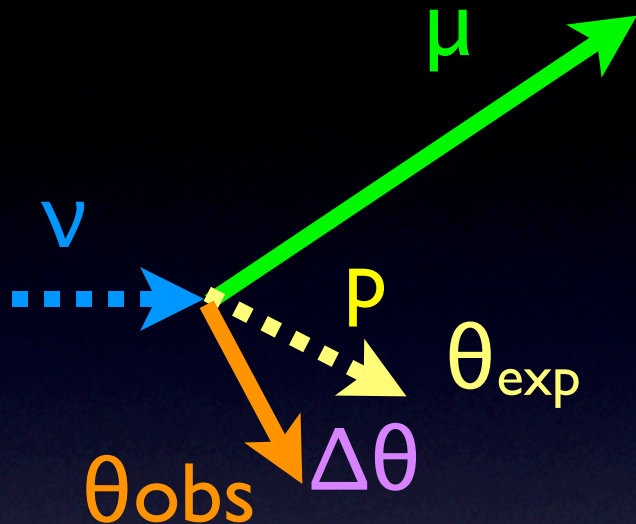
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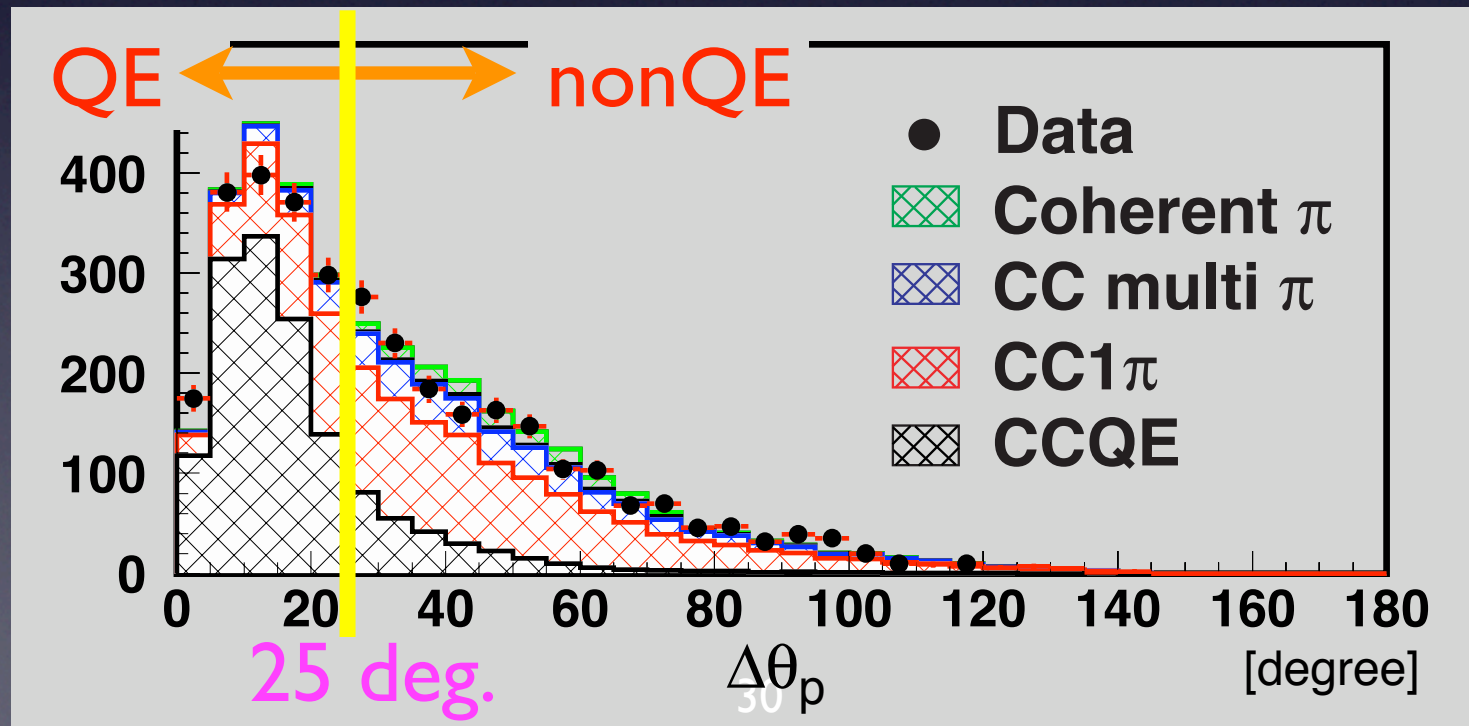
Event Selection



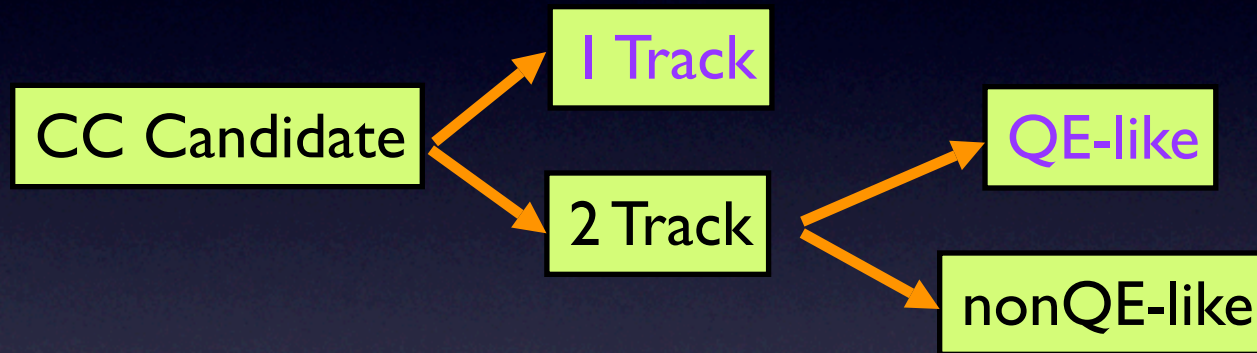
QE, or not QE?



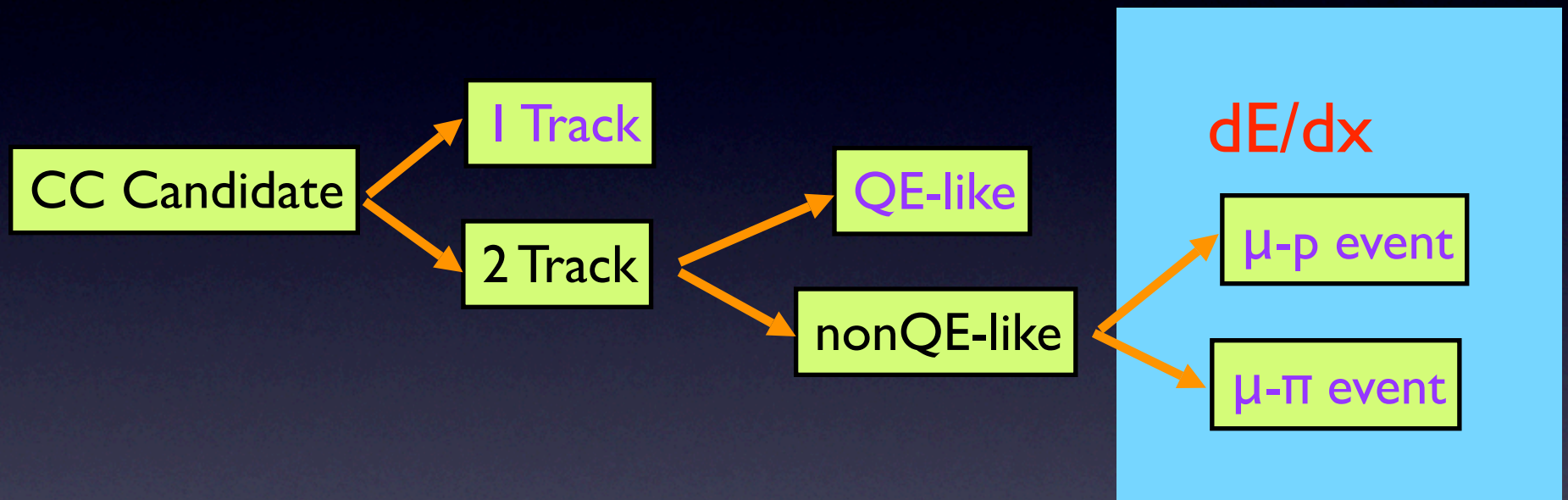
- CCQE: two-body interaction
- Difference b/w “**expected**” and “**observed**” angles of second (shorter) track assuming CCQE



Event Selection

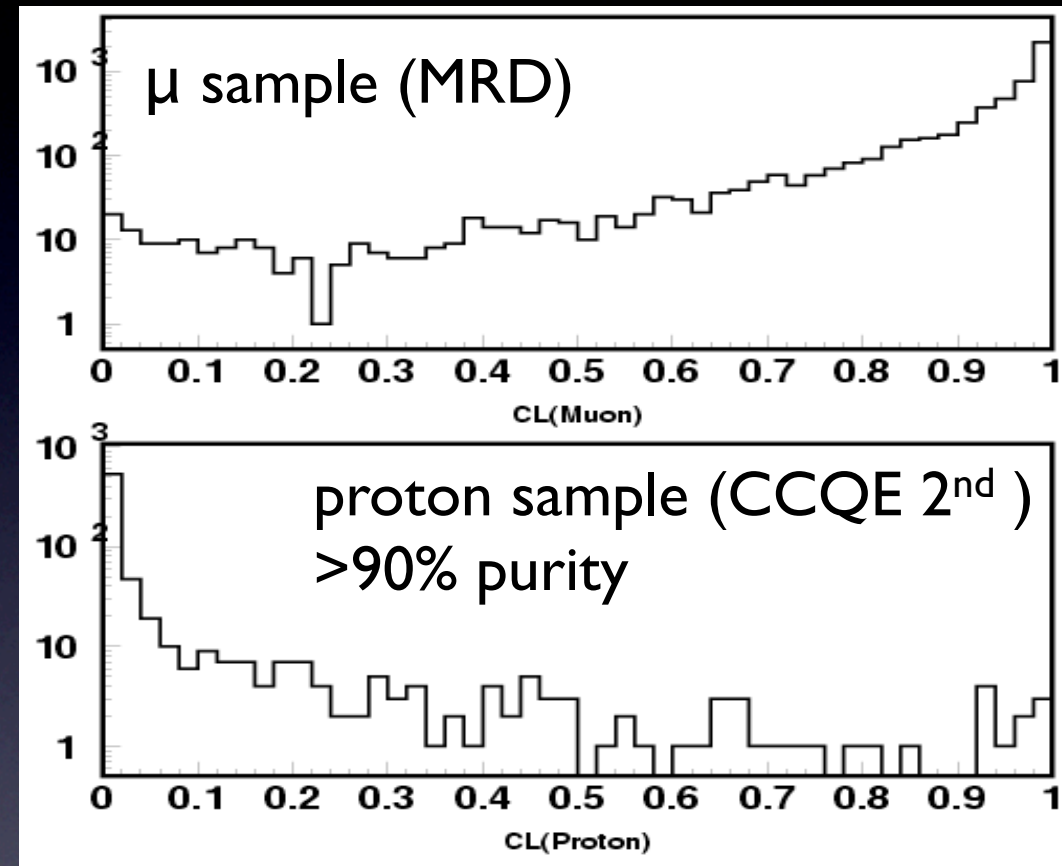


Event Selection



PID with dE/dx

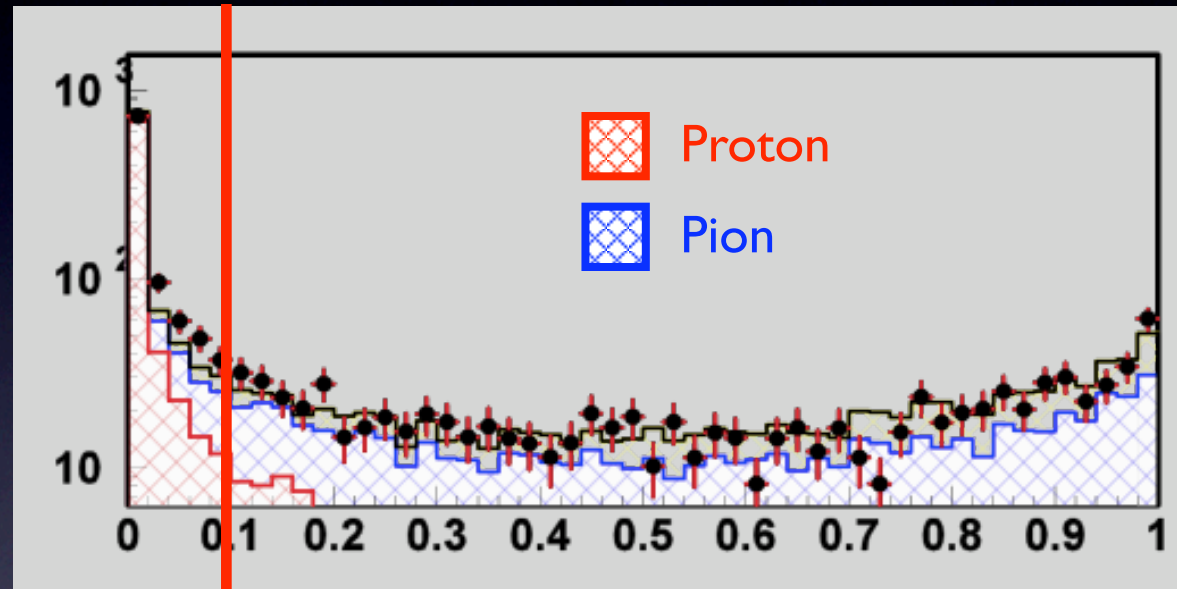
- “MIP likelihood” based on dE/dx
- Performance **verified with neutrino data**
- Clear separation of protons and MIPs
- Apply to non-QE sample
 - ✦ Cut at $L=0.1$



non-MIP
(proton) like \longleftrightarrow MIP-like

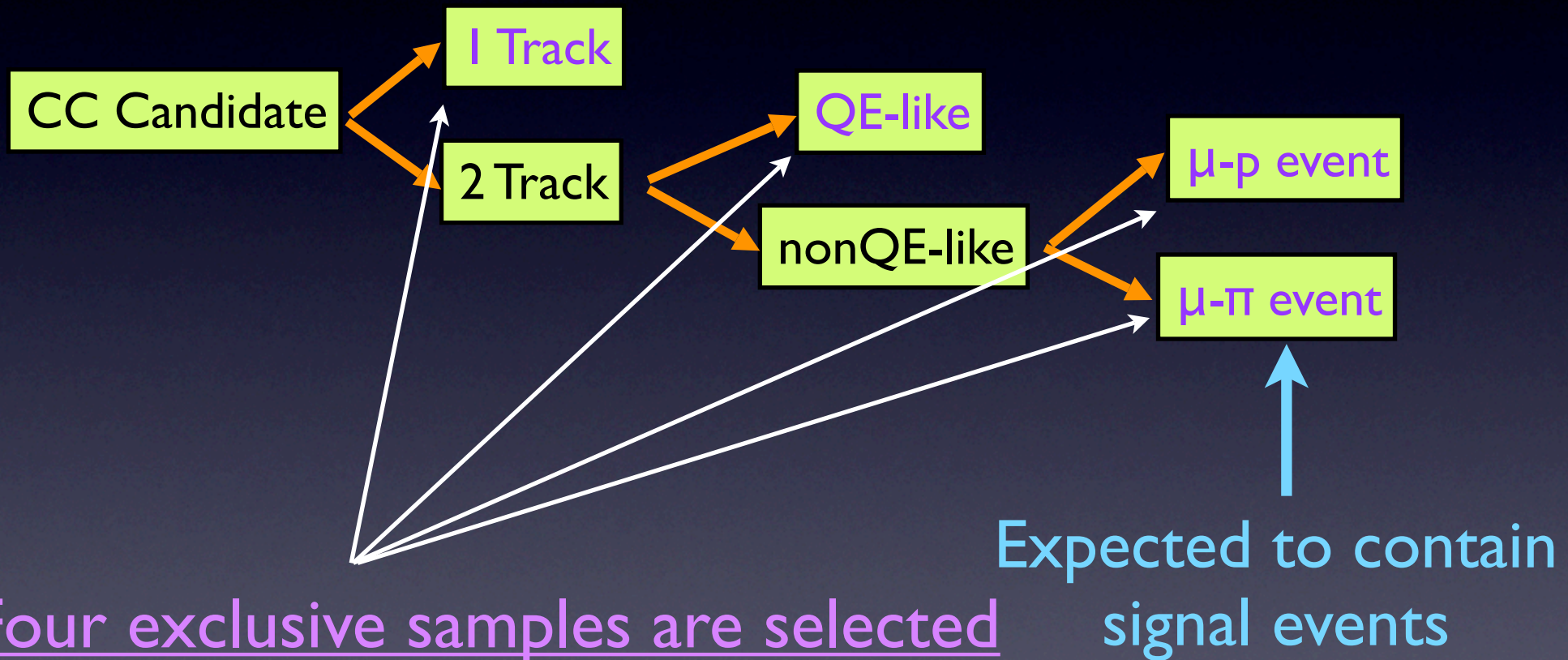
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Event categories



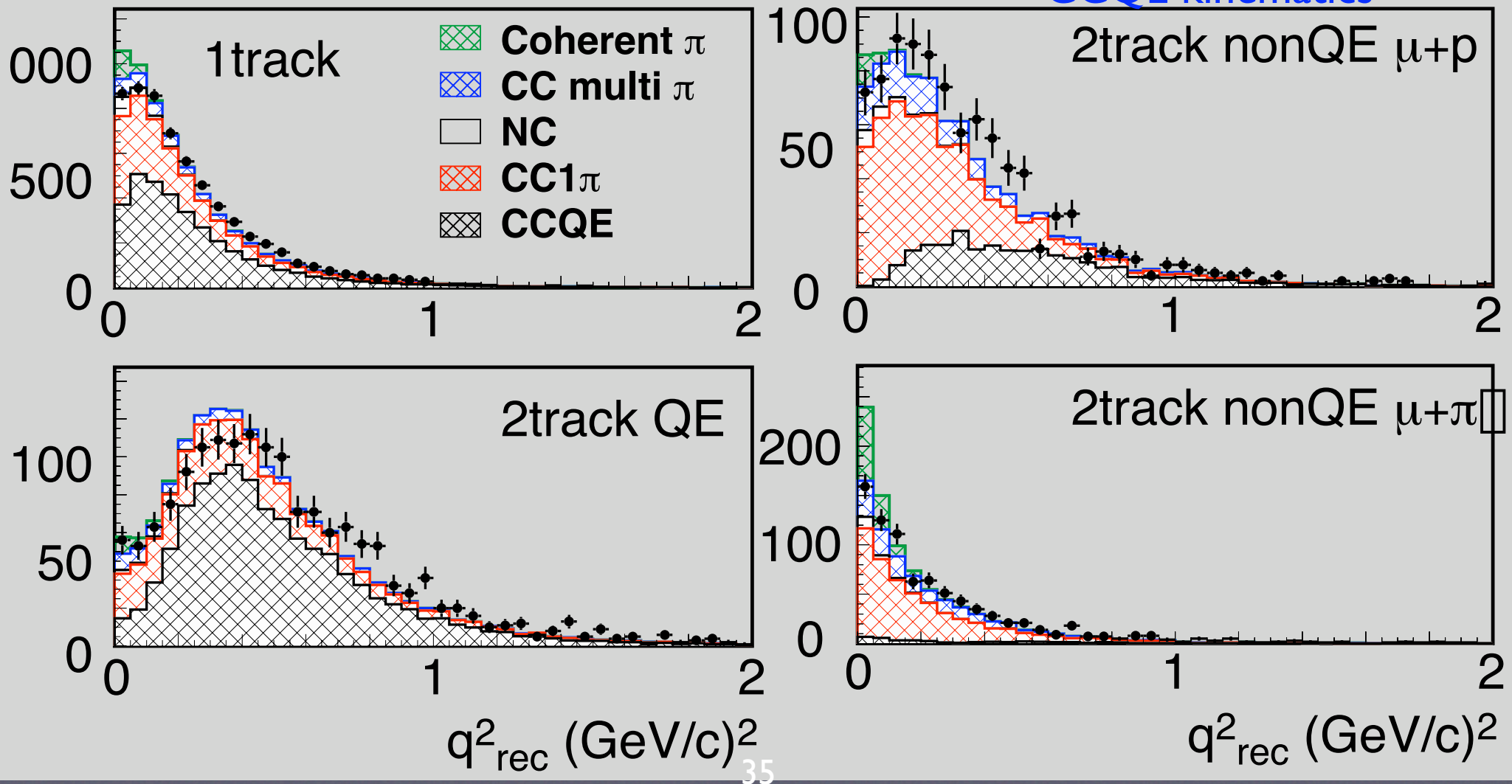
Uncertainties!

- Large uncertainties from ...
 - ✦ Neutrino interaction cross-sections
 - ✦ Nuclear effects (secondary interaction inside target nucleus)
 - Pion absorption / inelastic scattering
 - Proton rescattering
 - ✦ Detector systematics
- To constrain uncertainties, we fit q^2_{rec} distributions of data with MC expectation.

“Reconstructed q^2 ” distributions

with default MC

q^2_{rec} : from p_μ/θ_μ , assuming
CCQE kinematics

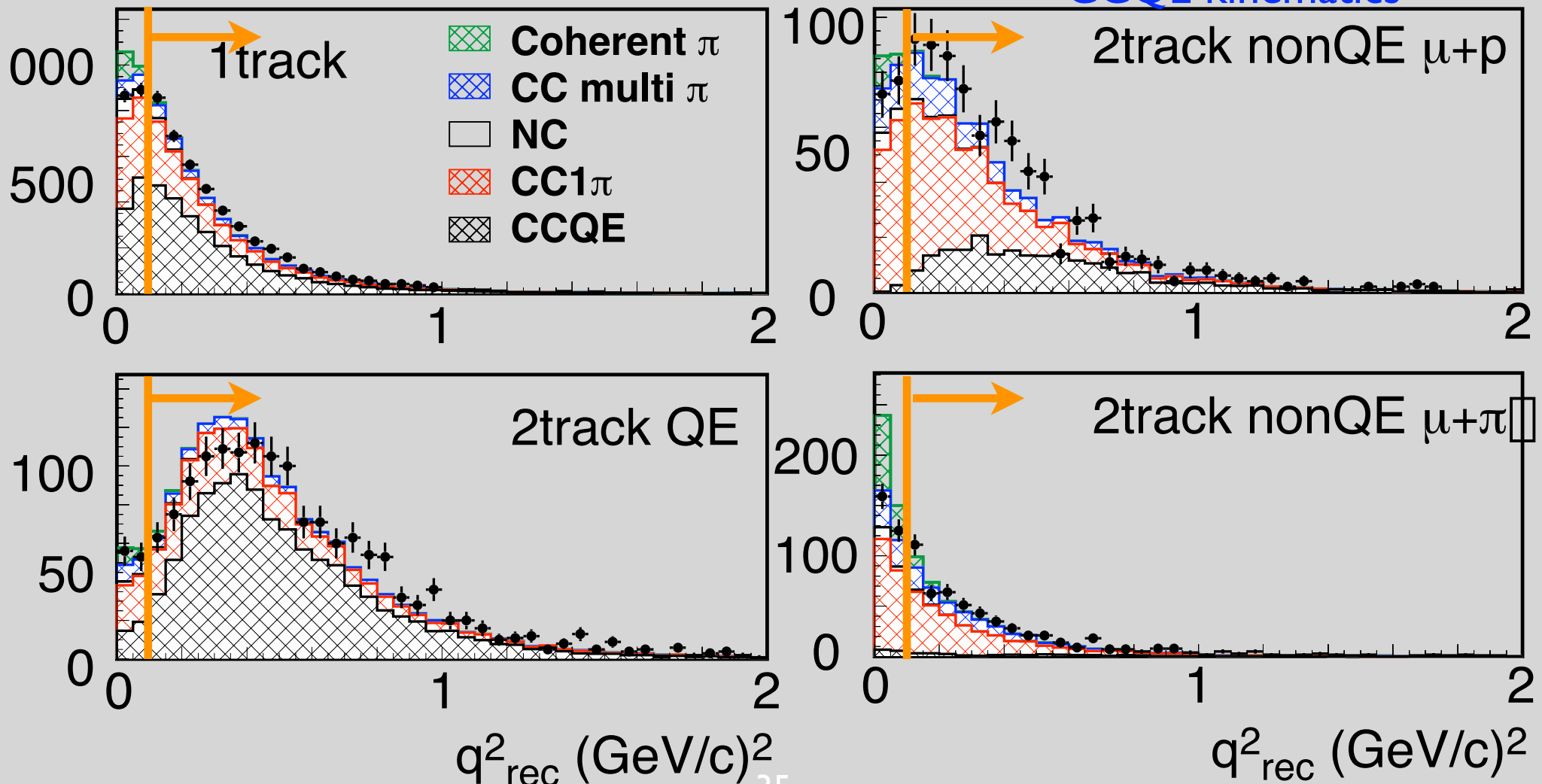


“Deconstructed q^2 ” distributions

Use $q^2_{\text{rec}} > 0.1 \text{ (GeV/c)}^2$
(non-signal region)

Fit four samples simultaneously

q^2_{rec} : from p_μ/θ_μ , assuming
CCQE kinematics



Constraining uncertainties

- Fitting parameters:

- ✦ non-QE/QE cross-section ratio

$R_{\text{nQE/QE}}$

- ✦ Muon momentum scale

R_{pscale}

- ✦ Normalization of each sub-sample

$f_{2\text{trk}/1\text{trk}}$

$f_{\text{nQE/QE}}$

$f_{\text{proton/pion}}$

1 Track

2trk non-QE, μ -p

2trk QE

2trk non-QE, μ - π

Constraining uncertainties

- Fitting parameters:

- ✦ non-QE/QE cross-section ratio
- ✦ Muon momentum scale
- ✦ Normalization of each sub-sample

constrained by
estimated uncertainties
and correlations

$R_{\text{nQE/QE}}$

R_{pscale}

$f_{2\text{trk}/1\text{trk}}$

$f_{\text{nQE/QE}}$

$f_{\text{proton/pion}}$

pion
absorption

1 Track

2trk non-QE, μ -p

2trk QE

2trk non-QE, μ - π

Constraining uncertainties

- Fitting parameters:

- ✦ non-QE/QE cross-section ratio
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$R_{\text{nQE/QE}}$

R_{pscale}

$f_{2\text{trk}/1\text{trk}}$

$f_{\text{nQE/QE}}$

$f_{\text{proton/pion}}$

pion
absorption
proton
rescattering

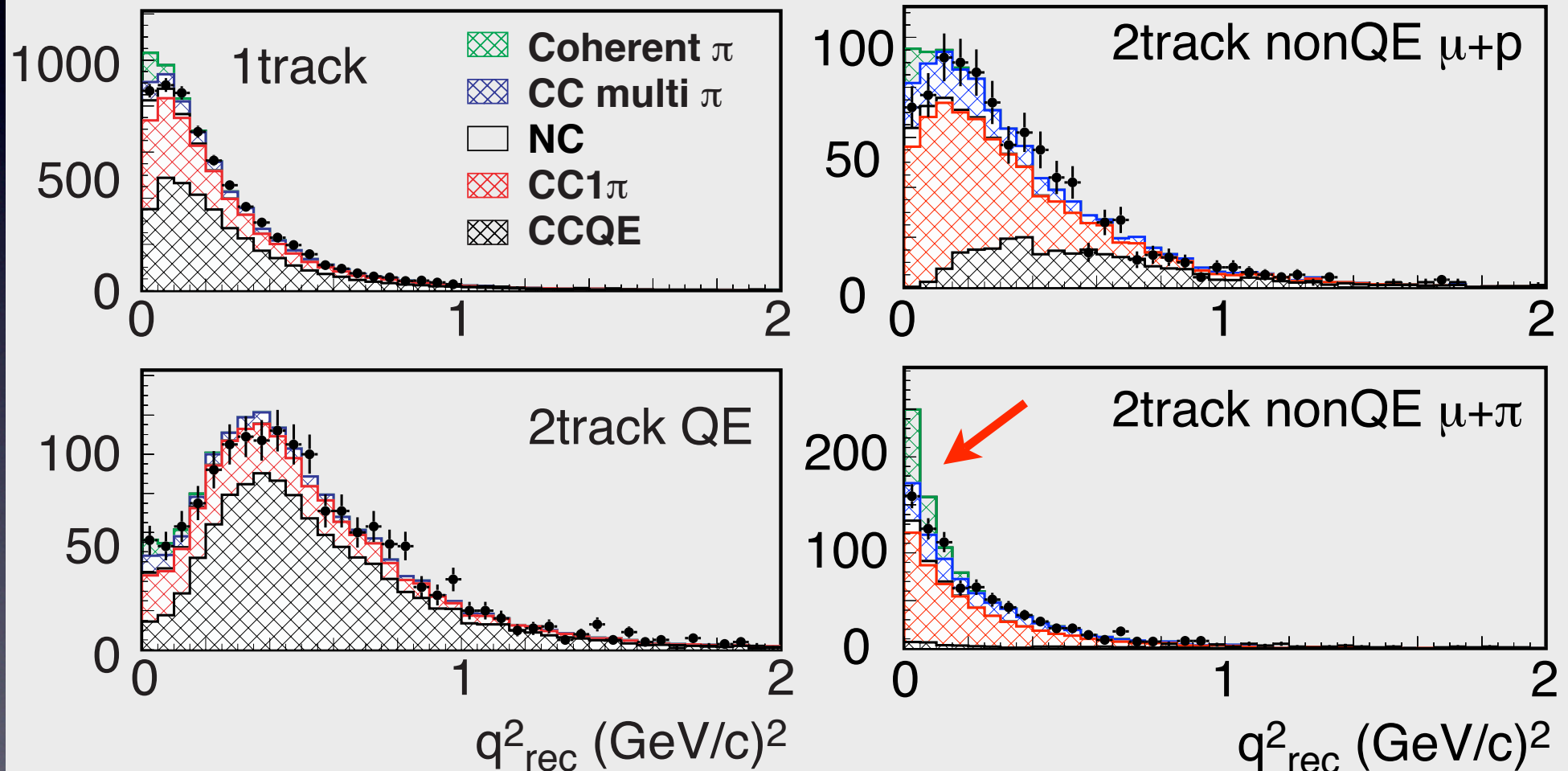


Fitting result

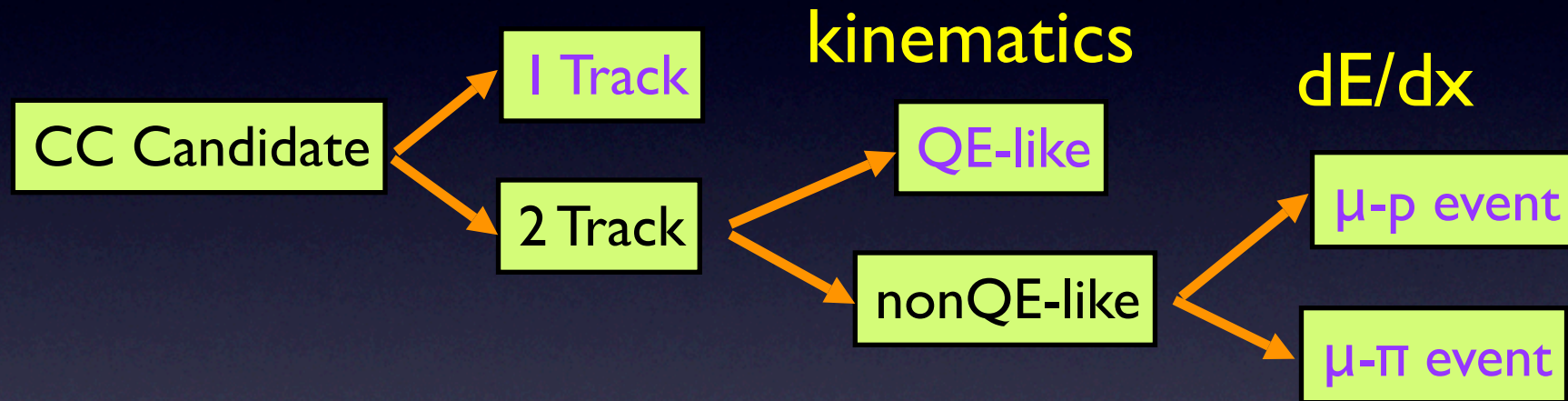
Parameter	Best fit value	Uncertainty after fit	Uncertainty before fit
$R_{nQE/QE}$	0.071	0.074	~0.2
R_{pscale}	-0.012	0.003	0.03
$f_{2trk/1trk}$	0.014	0.026	0.06
$f_{nQE/QE}$	0.043	0.054	0.09
$f_{proton/pion}$	0.079	0.051	0.14

- All parameters defined as **fractional deviation from the default MC**
- All values **stay within their estimated uncertainties**
- Errors propagated to the uncertainty of BG estimation

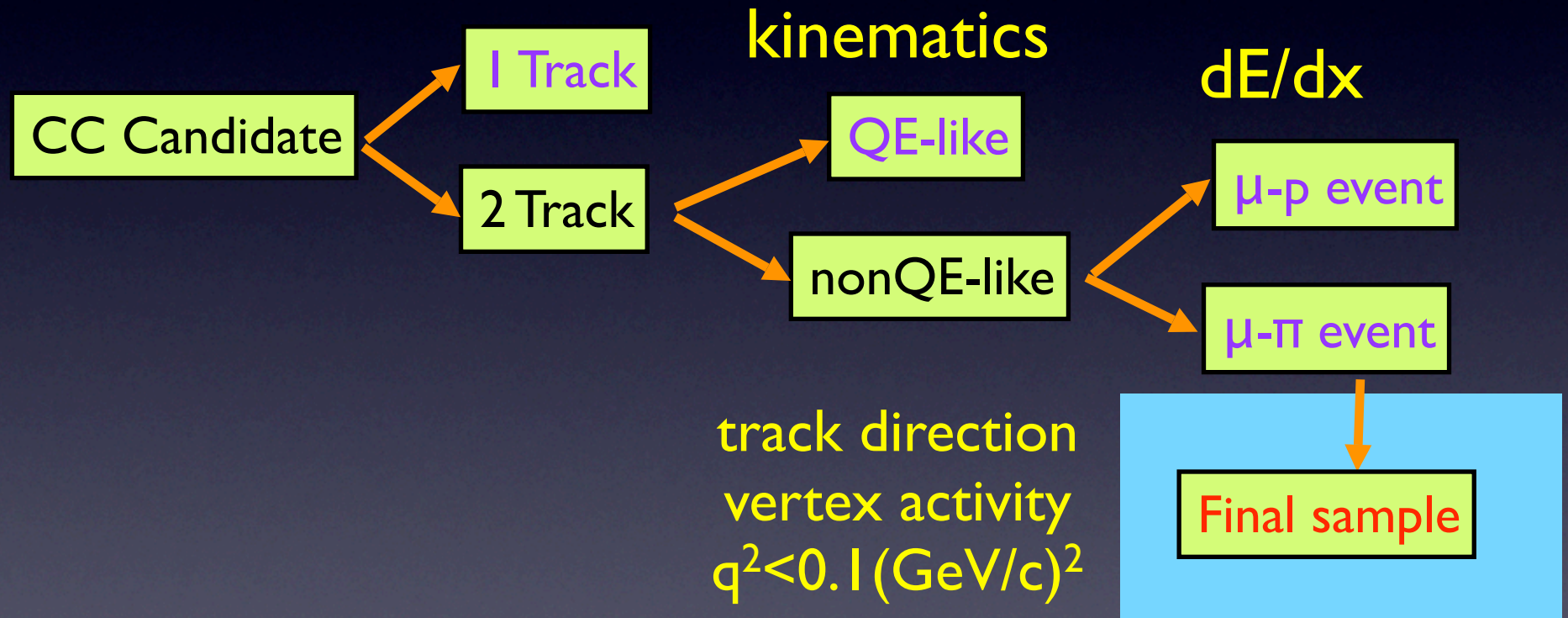
Reconstructed q^2 distributions after fitting



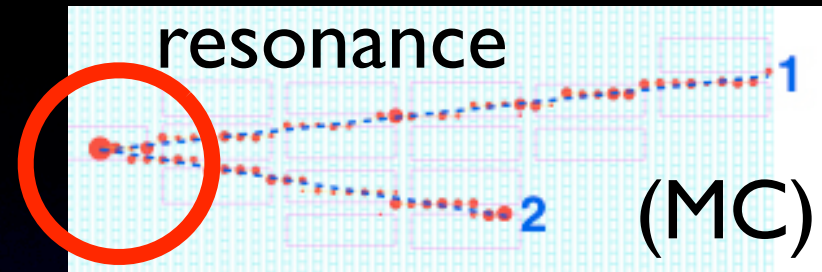
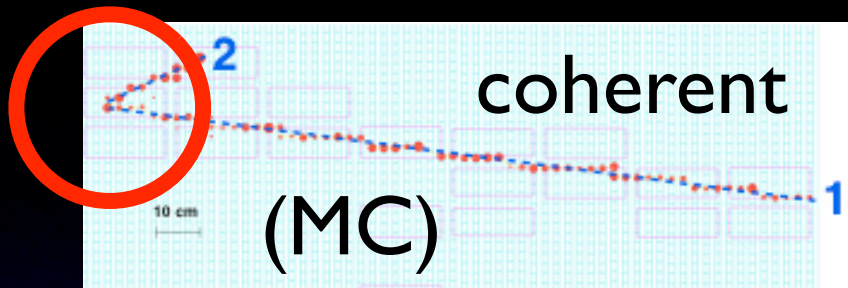
Event Selection



Event Selection

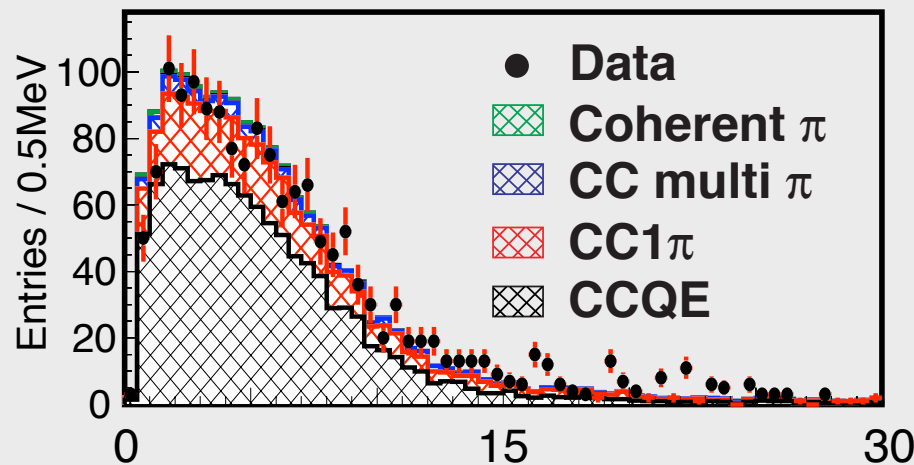


Activity in vertex strip

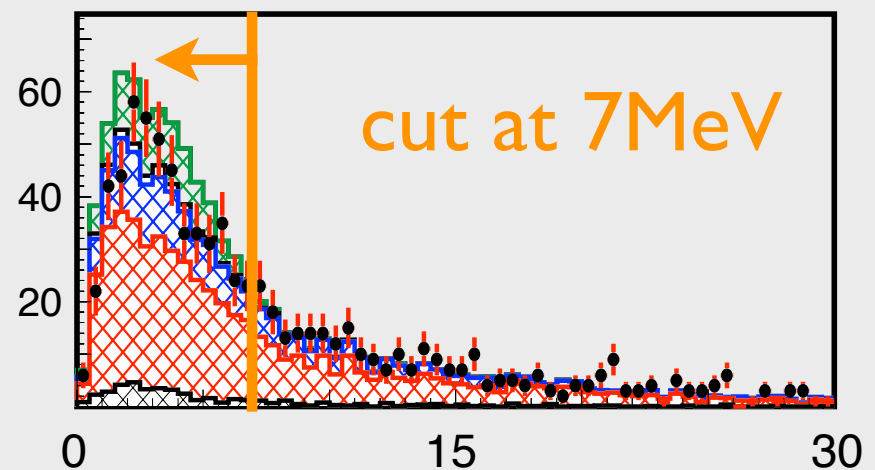


- Can reject BG with short track, even if not reconstructed
- MC verified with QE enriched sample (no “unknown” activity)

QE enriched



non-QE, mu+pi

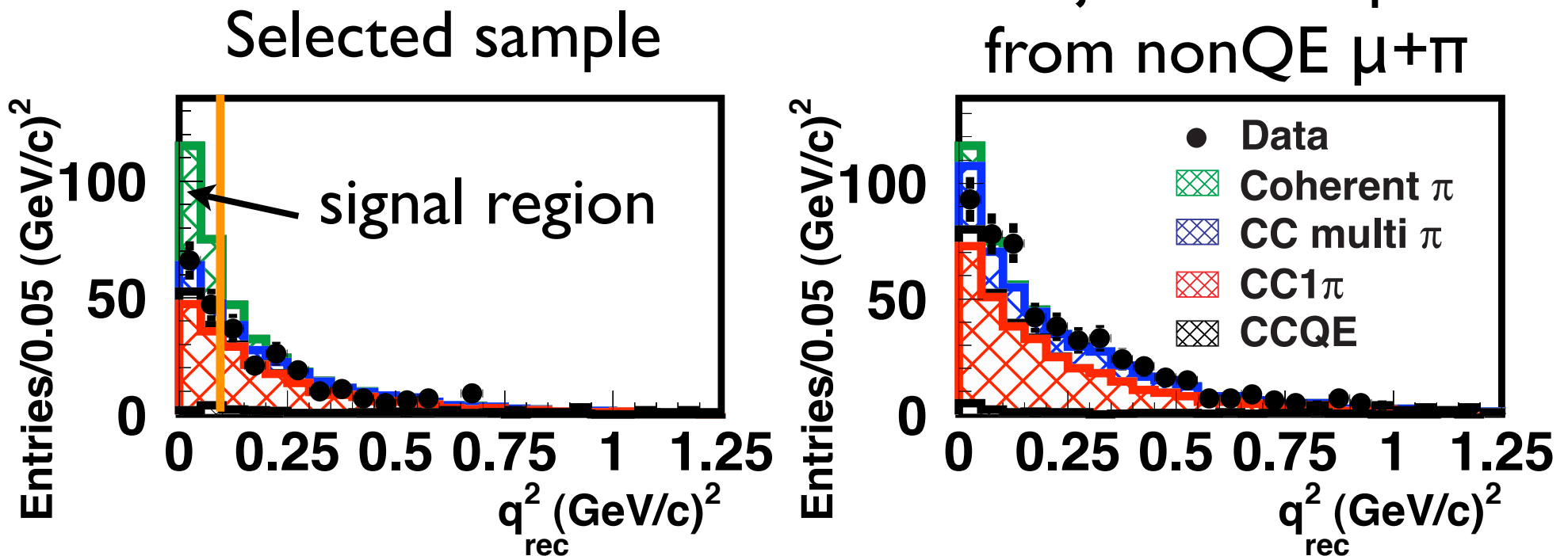


Event selection summary

	Data	Eff(%)	Purity
SciBar+MRD	10049	77.9	3.6
2track	3396	35.5	5.1
non-QE, mu+pi	843	27.7	14.8
Trk direction	773	27.3	15.8
Vtx activity	297	23.9	28.2
$q^2_{\text{rec}} < 0.1$	113	21.1	47.1

*efficiency/purity by MC, assuming R&S model for coherent pion

Final sample



- No evidence of CC coherent pion production in K2K-SciBar data.
- Estimated BG in signal region: 111.4 (113 obs.)
- Expected signal from R&S model: 98.7

Cross-section ratio

- CC sample (SciBar+MRD matching) is used for normalization.

✦ To avoid uncertainties from neutrino flux

$$\begin{array}{l} N_{\text{obs}}^{\text{CC}} = 10049 \\ \text{Purity: } 0.980 \\ \text{Efficiency: } 0.569 \end{array} \quad \longrightarrow \quad N^{\text{CC}} = 17.3 \pm 0.2(\text{stat.}) \times 10^3$$

Cross-section ratio

- CC sample (SciBar+MRD matching) is used for normalization.

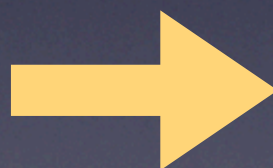
✦ To avoid uncertainties from neutrino flux

$N_{\text{obs}}^{\text{CC}} = 10049$
Purity: 0.980
Efficiency: 0.569



$$N^{\text{CC}} = 17.3 \pm 0.2 (\text{stat.}) \times 10^3$$

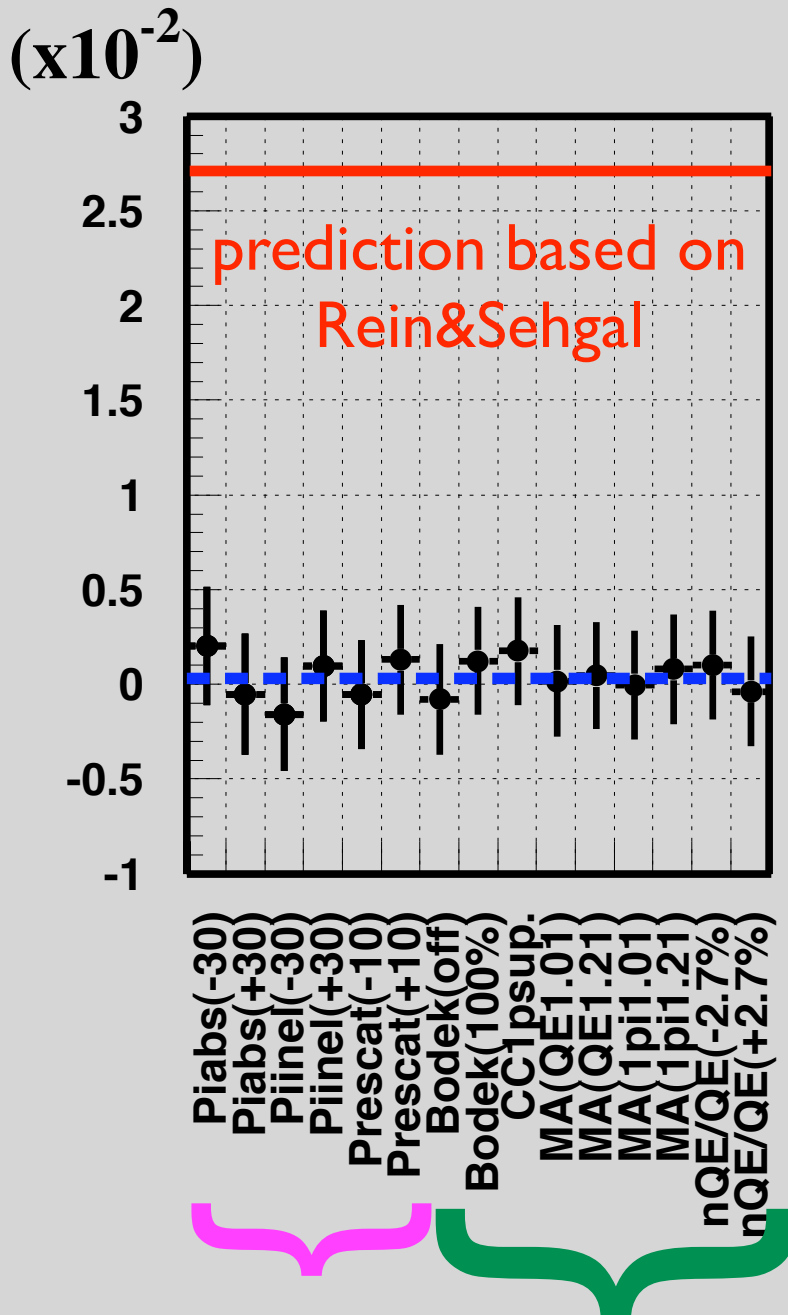
$N_{\text{obs}}^{\text{final}} = 113$
exp. BG: 111.4
Efficiency: 0.211



$$N^{\text{CC-coh}} = 7.6 \pm 50.4$$

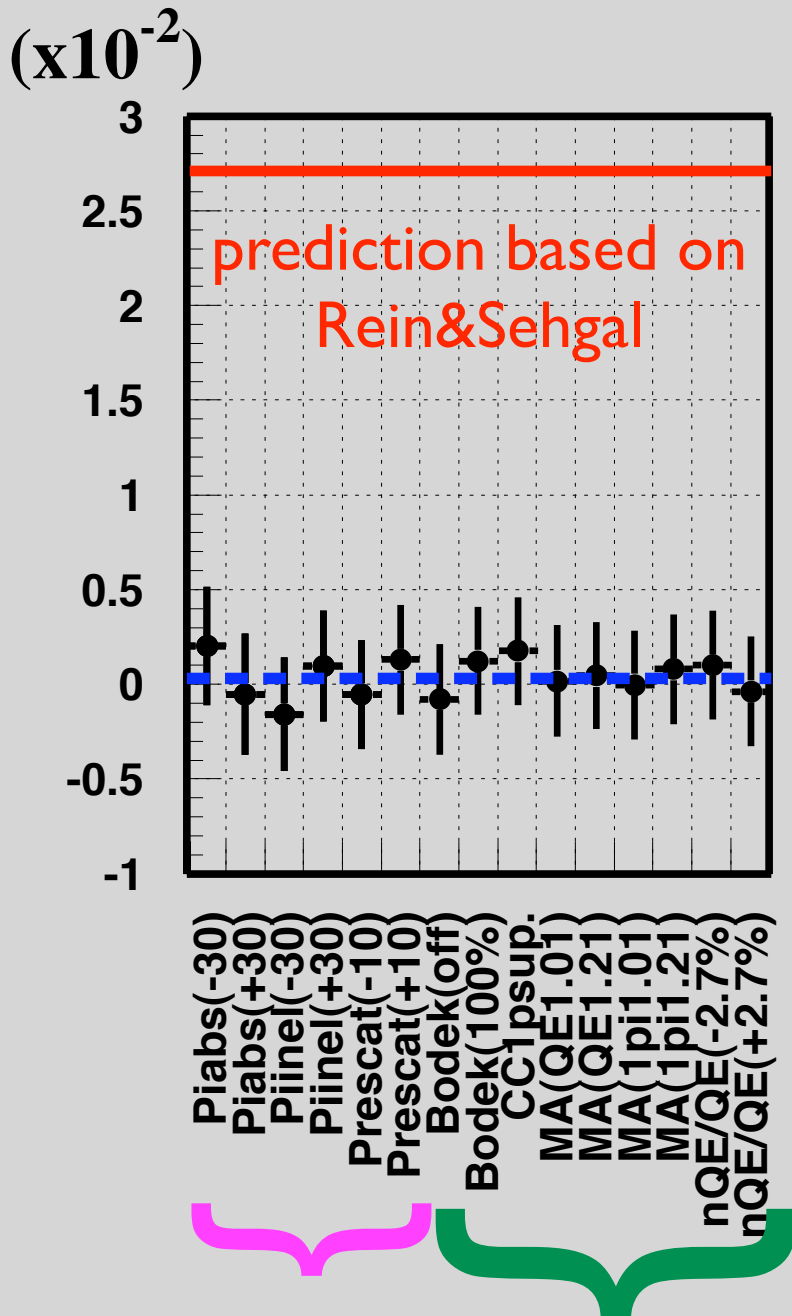
(corresponding MC prediction w/ R&S: 470)

Systematic uncertainties

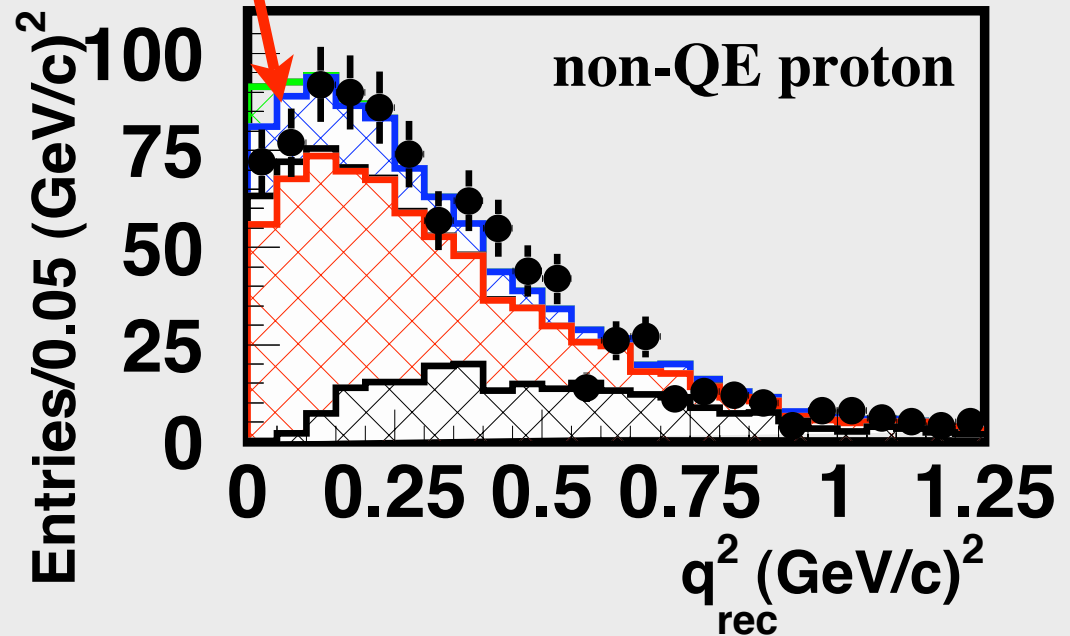


	Uncertainties ($\times 10^{-2}$)	
	Positive	Negative
Nuclear effects	0.23	0.24
Neutrino interaction	0.10	0.09
CC1pi suppression	0.14	-
Event selection	0.11	0.17
Detector response	0.09	0.16
Neutrino energy spectrum	0.03	0.03
Total	0.32	0.35

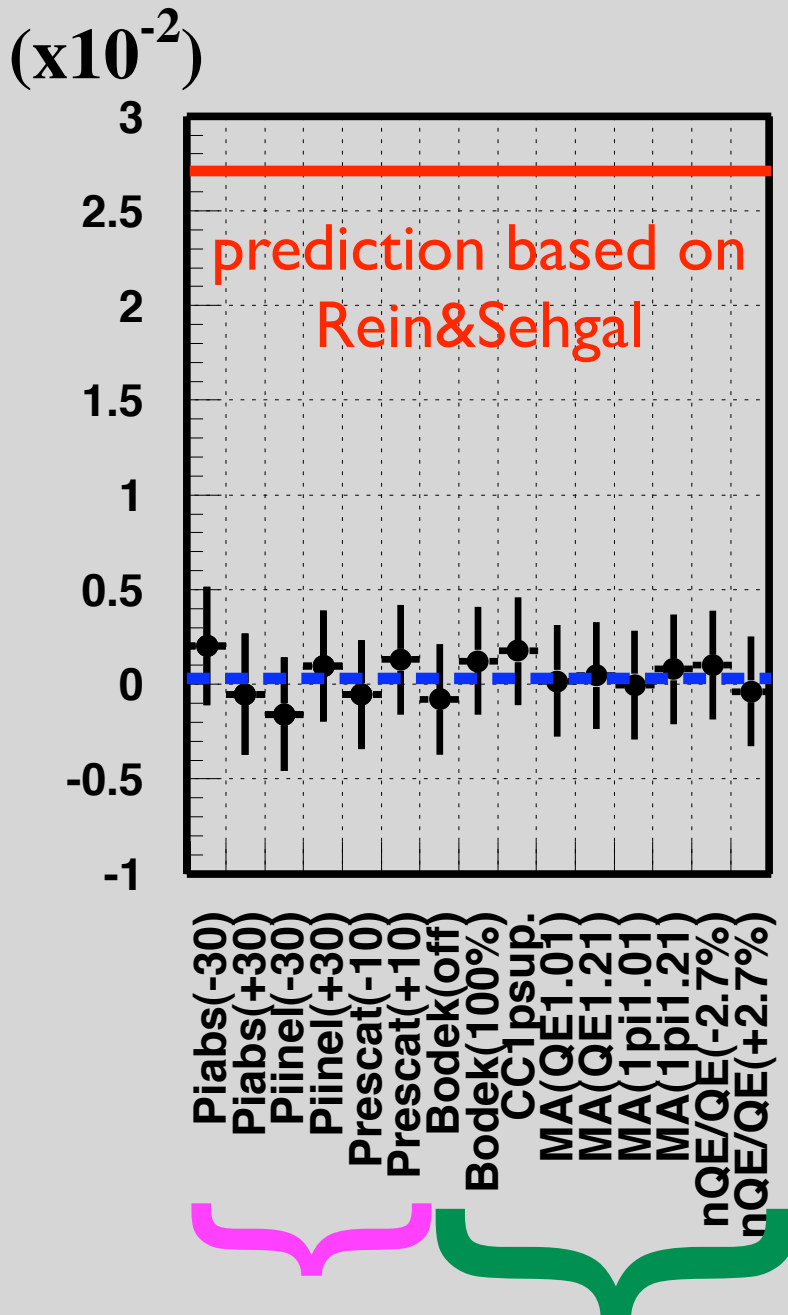
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Result

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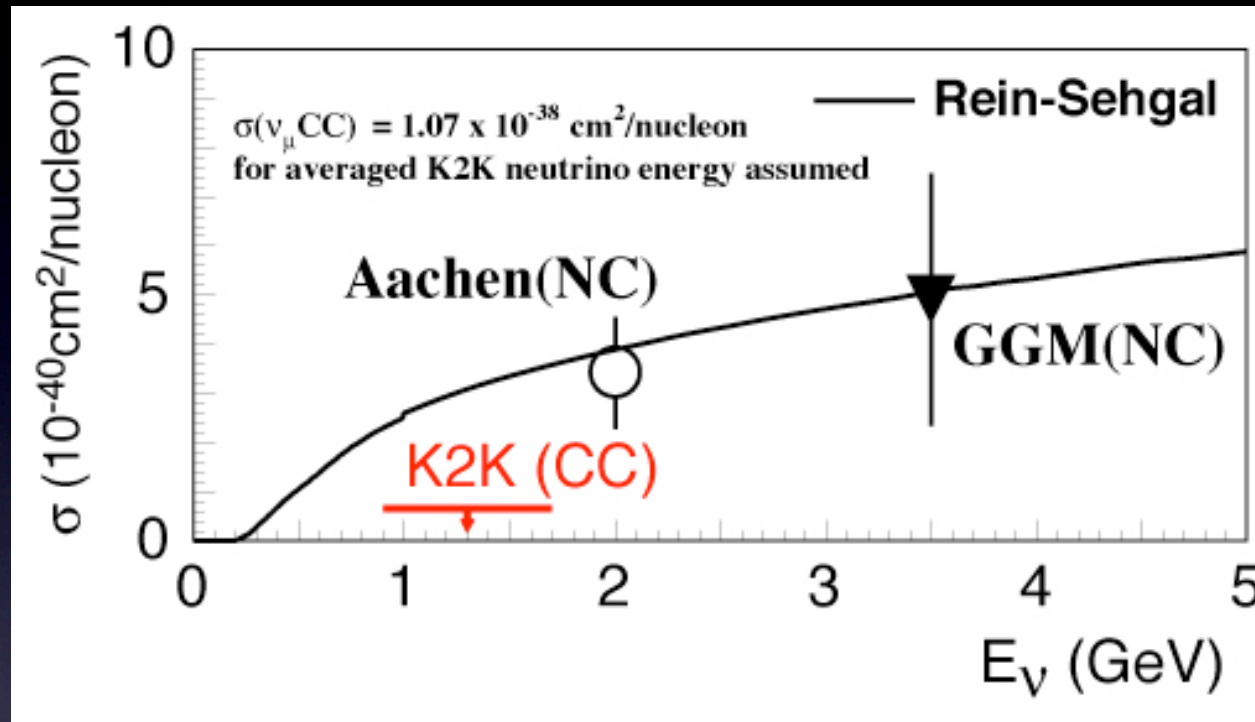
$$\sigma(\text{CC coherent})/\sigma(\text{CC total}) = [0.04 \pm 0.29(\text{stat.}) + 0.32 - 0.35(\text{syst})] \times 10^{-2}$$

90% CL upper limit: 6.0×10^{-3}

M.Hasegawa* et al. (K2K)
Phys. Rev. Lett. 95, 252301 (2005)

*Kyoto grad. student

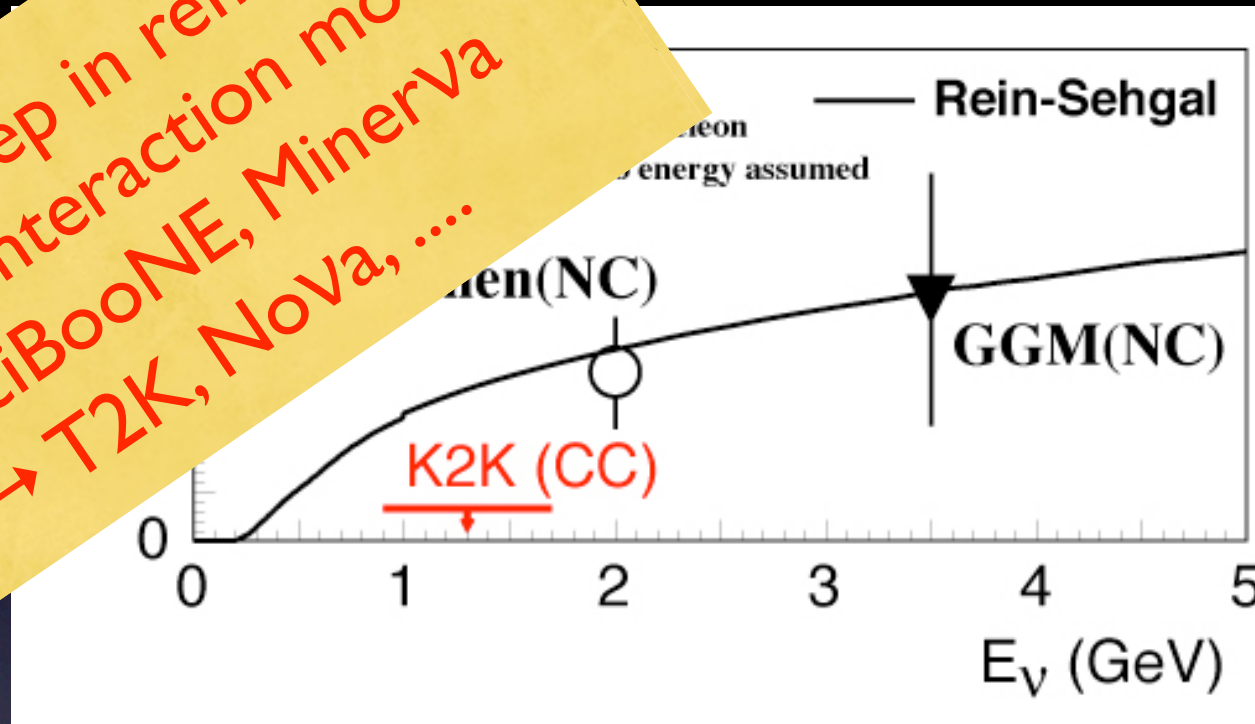
Comparison with other results



- **Assumptions:**
 - ✦ $\sigma(\text{CC}) = 2\sigma(\text{NC})$ (isospin relations)
 - ✦ σ proportional to $A^{1/3}$ for different nucleus
 - ✦ $\sigma(\text{total CC})$ in NEUT MC

Comparison with other results

Great step in refining
neutrino interaction model!
→ SciBooNE, Minerva
→ T2K, Nova,



- **Assumptions:**
 - ✦ $\sigma(\text{CC}) = 2\sigma(\text{NC})$ (isospin relations)
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 - ✦ $\sigma(\text{total CC})$ in NEUT MC

Results from K2K&SciBar detector

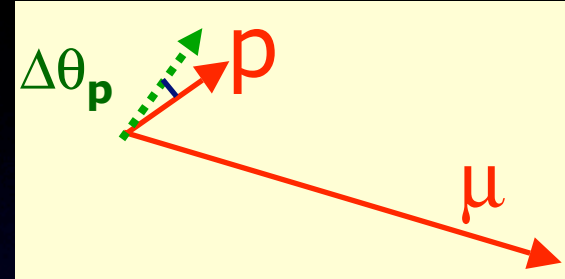
- Search for coherent charged pion production
- Final result from ν_μ disappearance analysis

Measurement of neutrino energy spectrum at near detectors

Used Data for Spectrum Meas.

1KT

(1) Fully Contained
1 ring μ -like events



SciFi

(2) 1-track μ events
(3) 2-track QE-like
(4) 2-track nonQE-like

SciBar

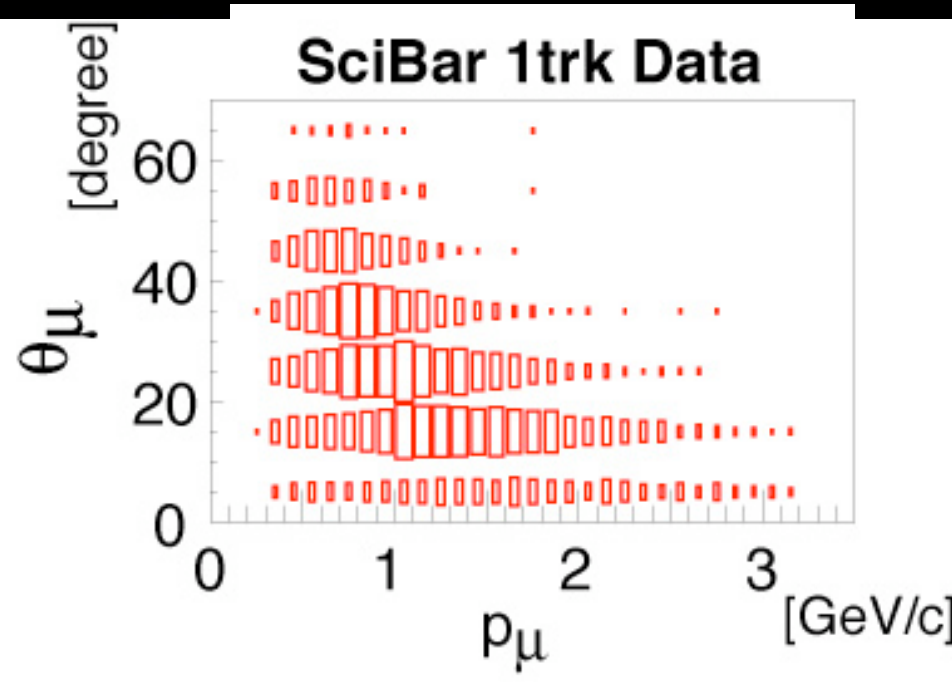
(5) 1-track μ events
(6) 2-track QE-like
(7) 2-track nonQE-like

7 sets of (p_μ, θ_μ) distributions



- ν spectrum $\Phi_{\text{Near}}(E_\nu)$ (8 bins)
- ν interaction model (nQE/QE)

Actual procedure E_ν QE (MC) nQE(MC)

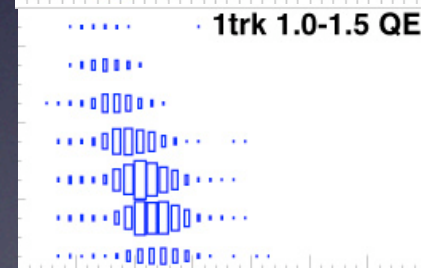
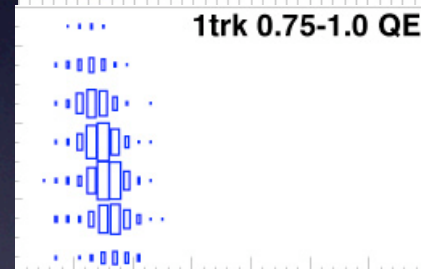
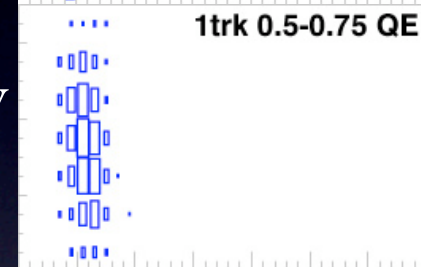
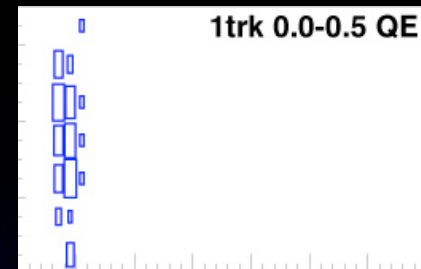


0-0.5 GeV

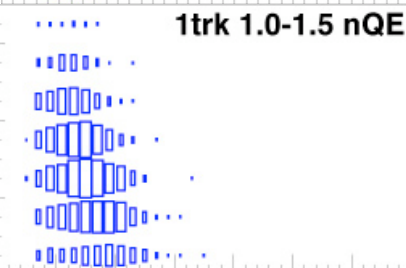
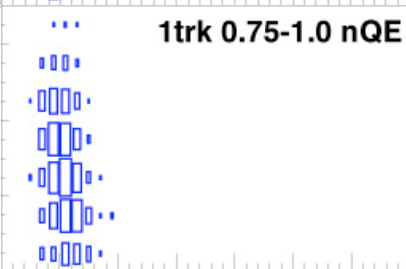
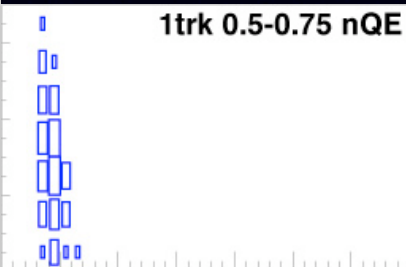
0.5-0.75 GeV

0.75-1.0 GeV

1.0-1.5 GeV



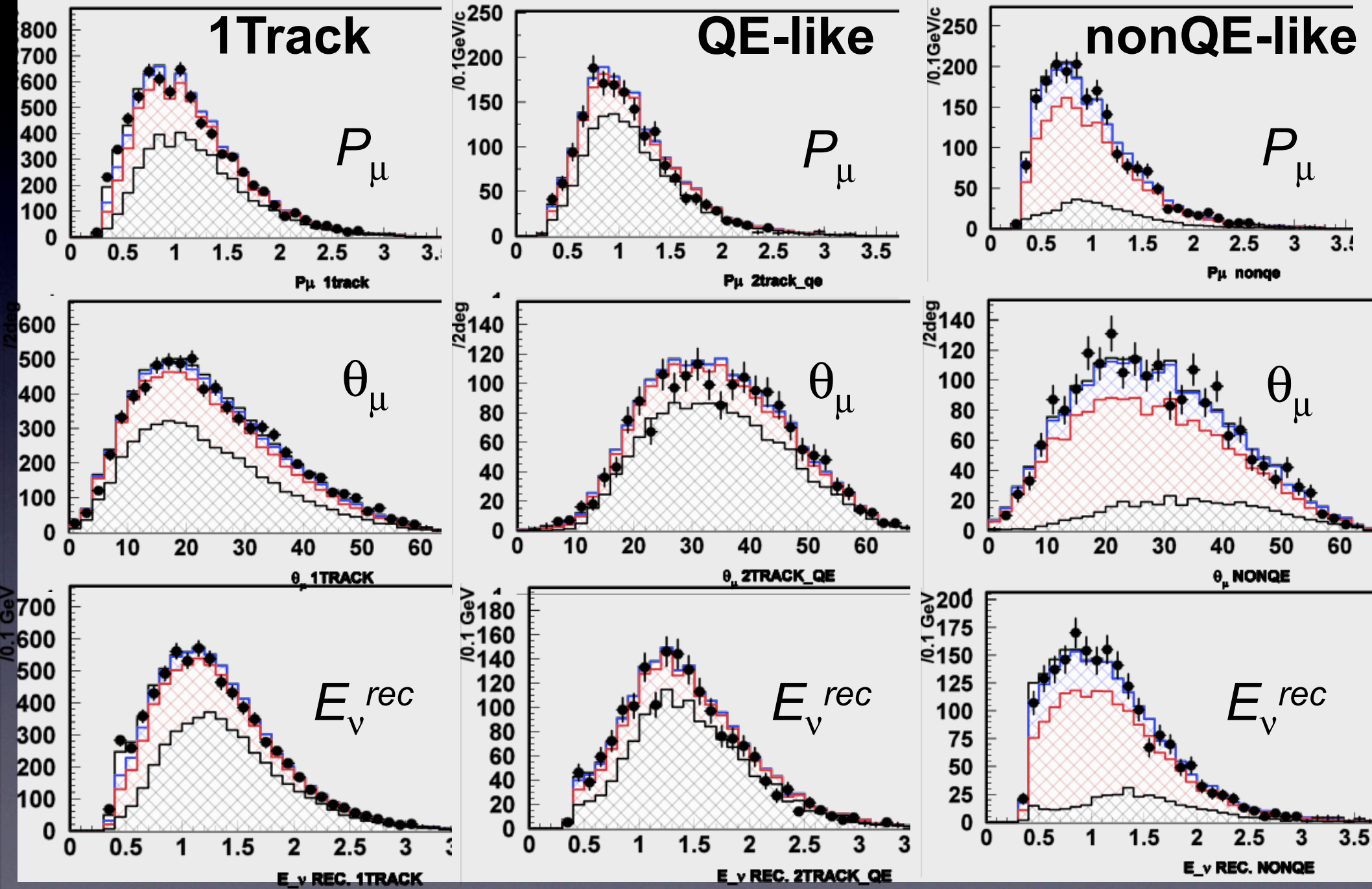
MC templates



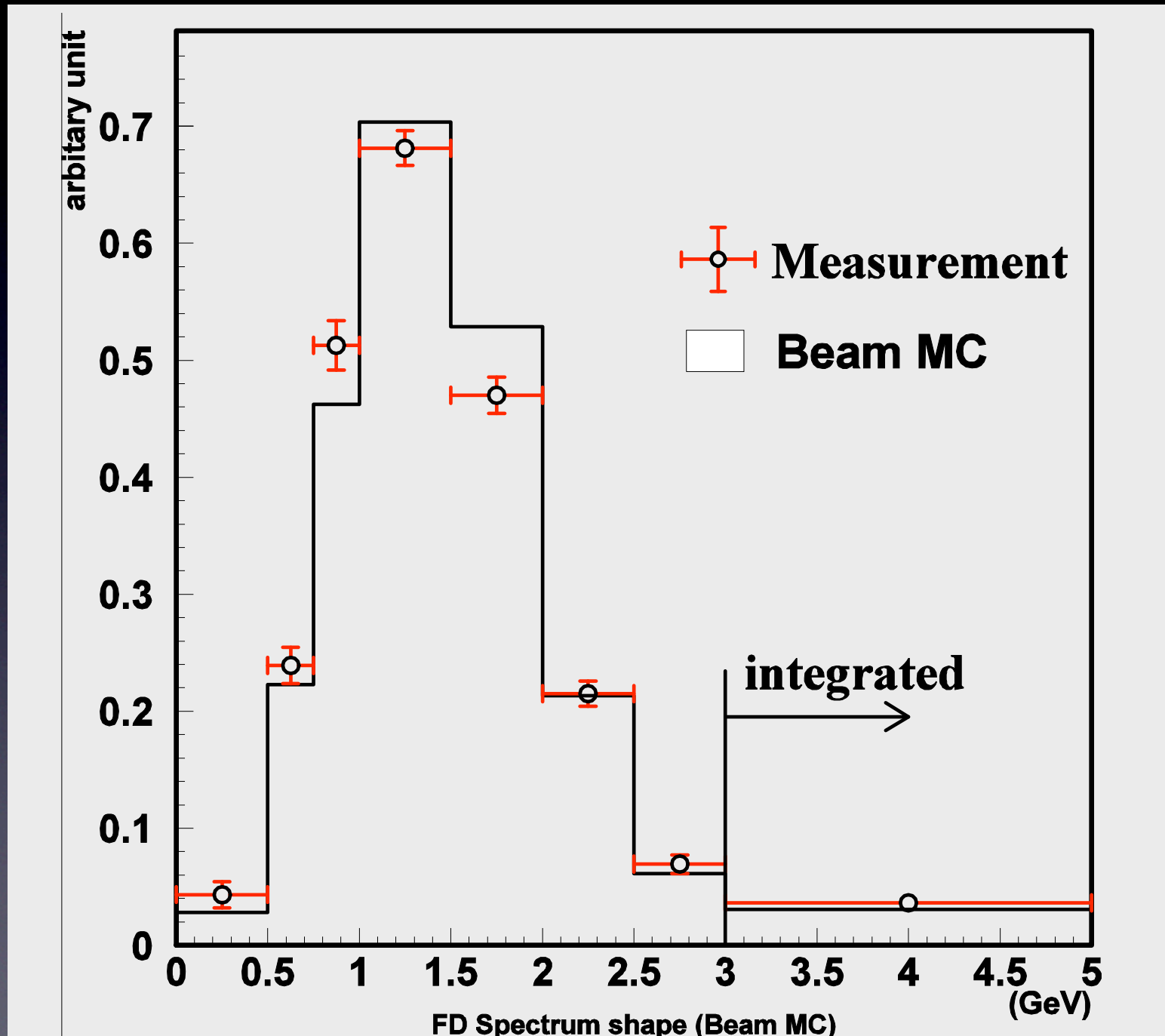
Seven sub-samples are simultaneously fitted.

- ν spectrum $\Phi_{\text{KEK}}(E_\nu)$ (8 bins)
- ν interaction (nQE/QE)

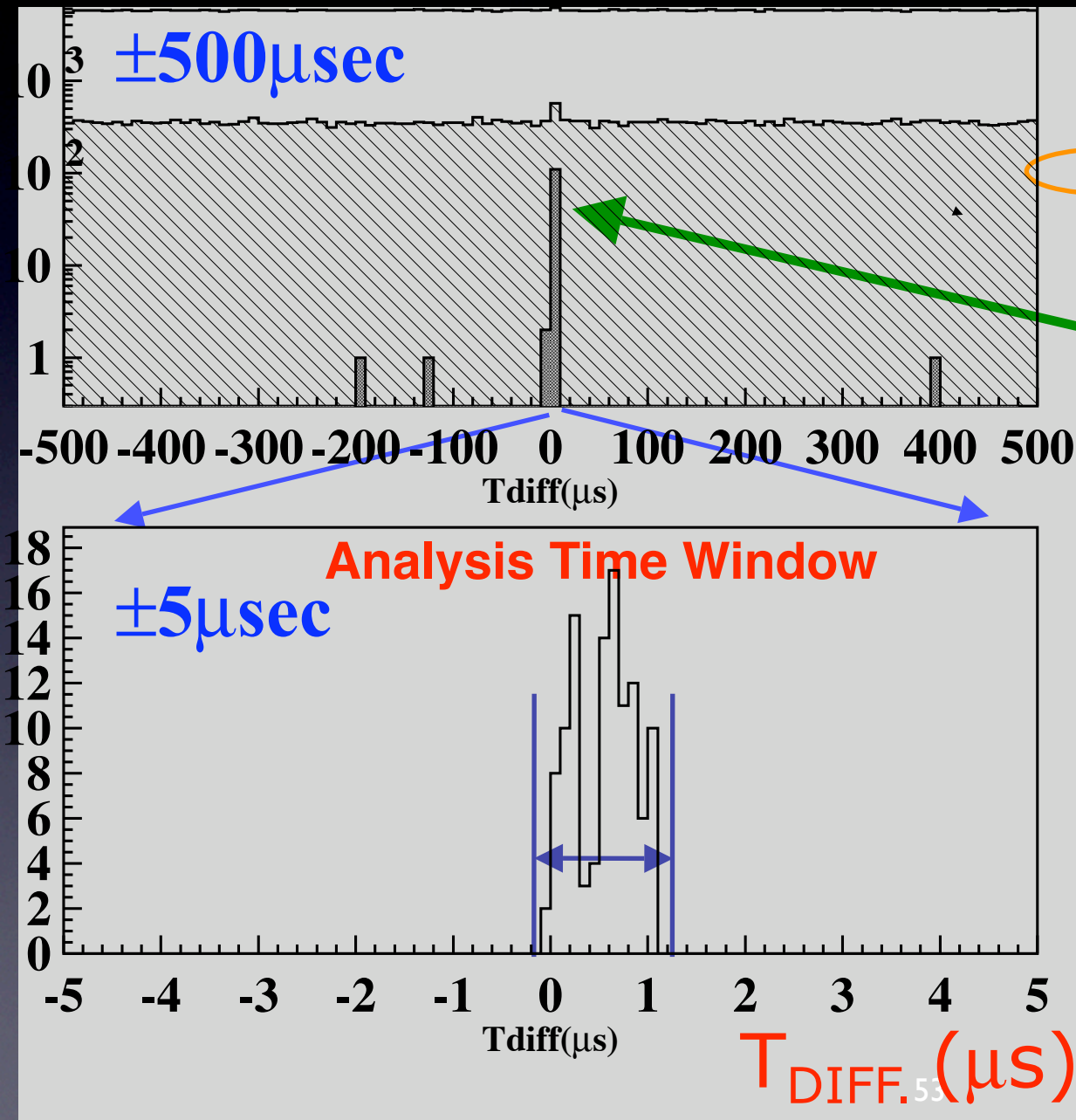
Distributions after Fitting



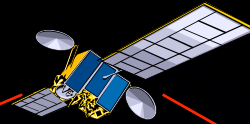
Measured energy spectrum



Super-K Event Selection



GPS



T_{spill} $TOF=0.83msec$ T_{SK}

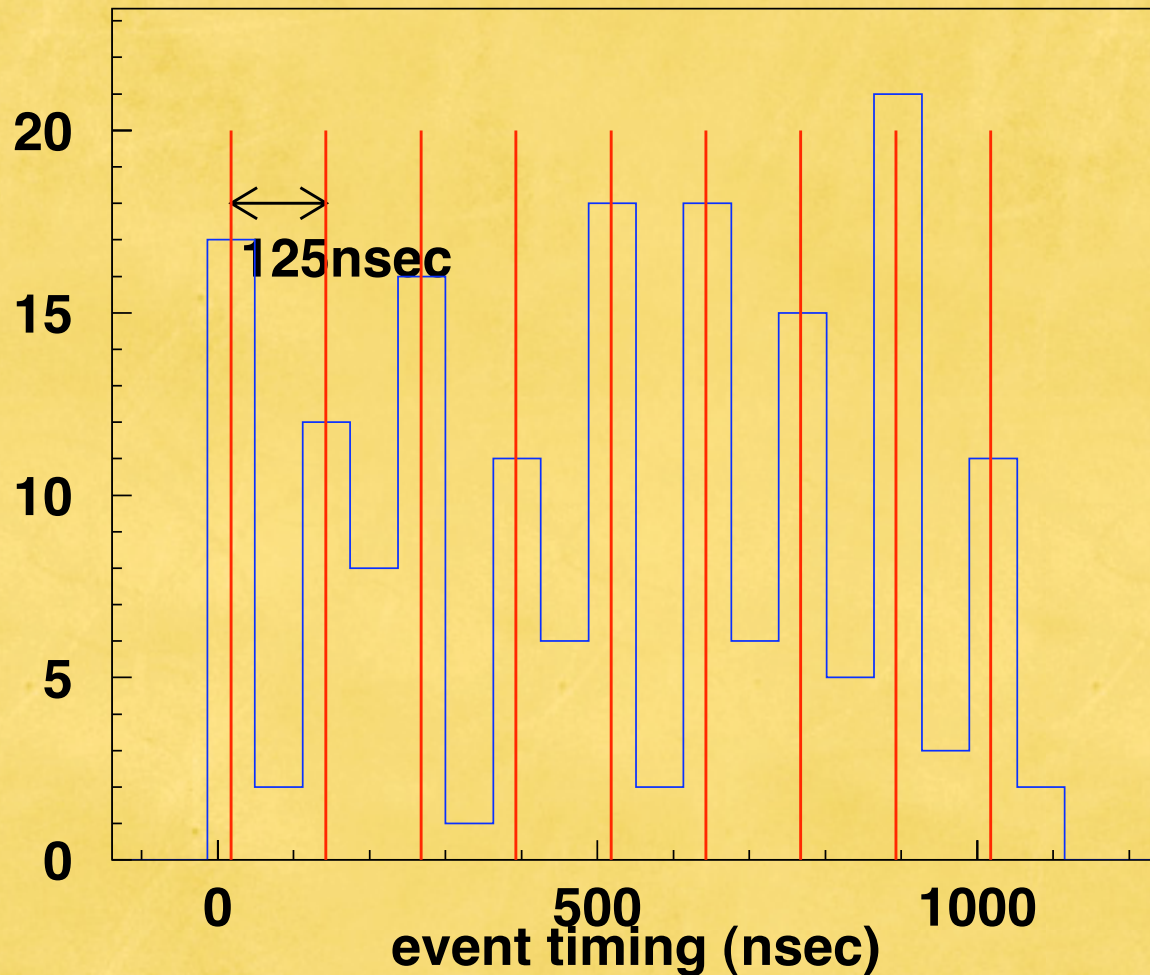
Fully contained in
22.5kt fiducial volume

112 events

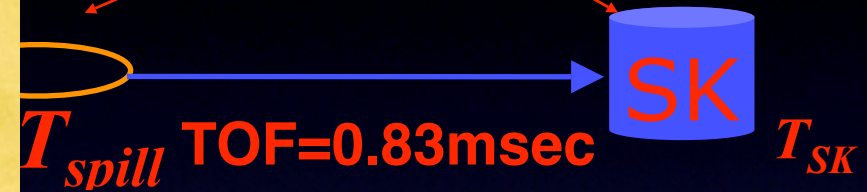
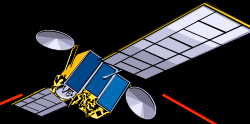
in $1.5 \mu sec$ window
w/ negligible (2×10^{-3})
background

Super-K Event Selection

SK event timing (1bin=125/2 (nsec))



GPS

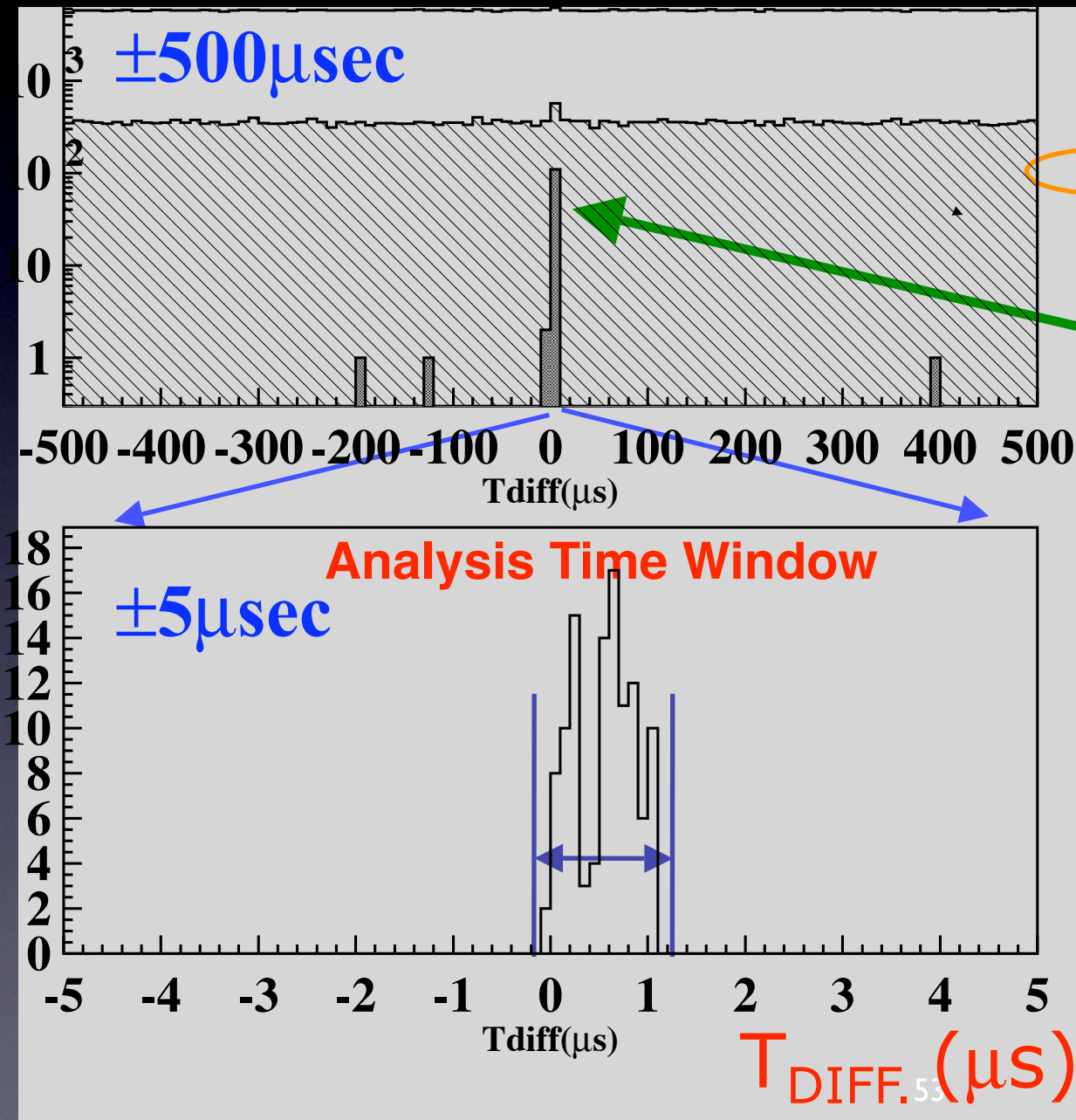


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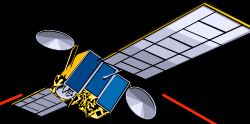
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background

Super-K Event Summary

Total number of events

	N _{obs}	N _{pred}
ALL	112	158.4
l-ring	67	101.0
mu-like	58	92.7
e-like	9	8.3
multi-ring	45	57.4

Used for energy reconstruction

Oscillation results

Oscillation results

- **Final result** from K2K using:

Oscillation results

- **Final result** from K2K using:
 - ✦ **Full data** set (9.2×10^{19} POT)

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Oscillation results

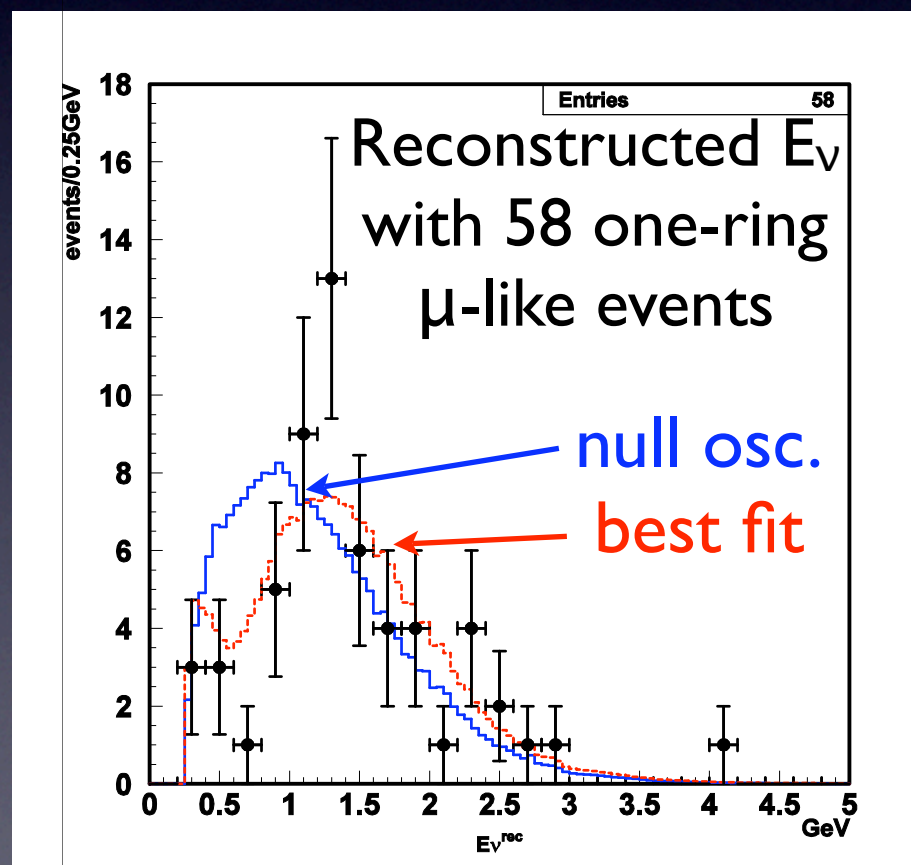
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 - ✦ Released in Jan. 2006

Oscillation results

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- 158.4^{+9.4}_{-8.7}** expected
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Oscillation results

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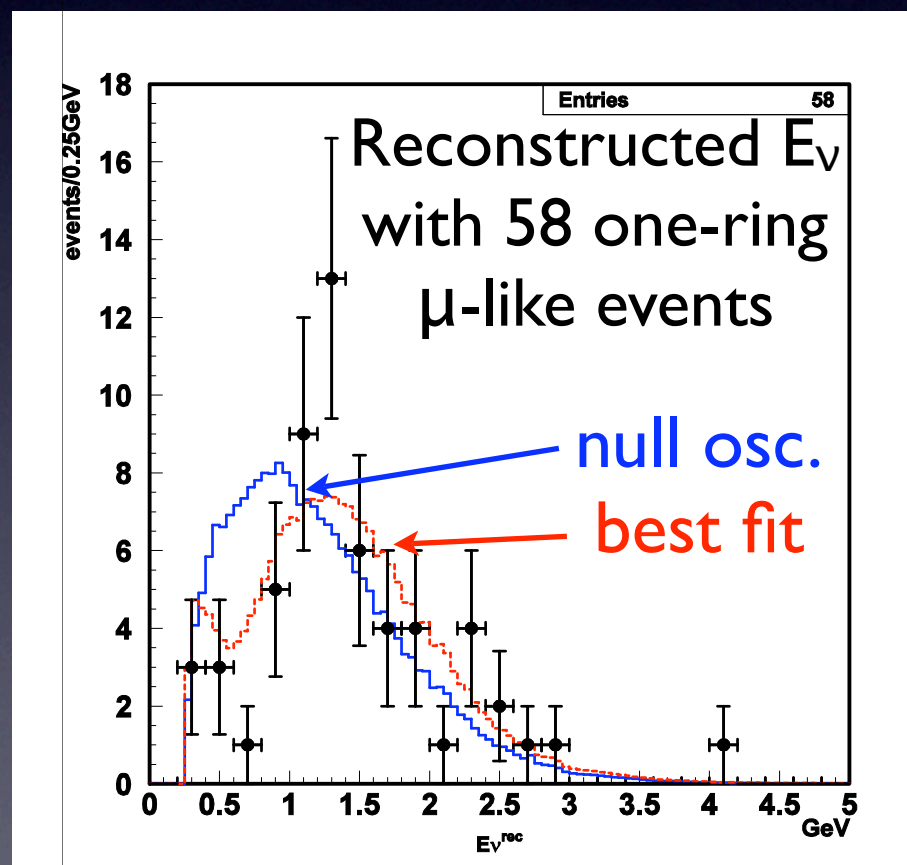


Oscillation results

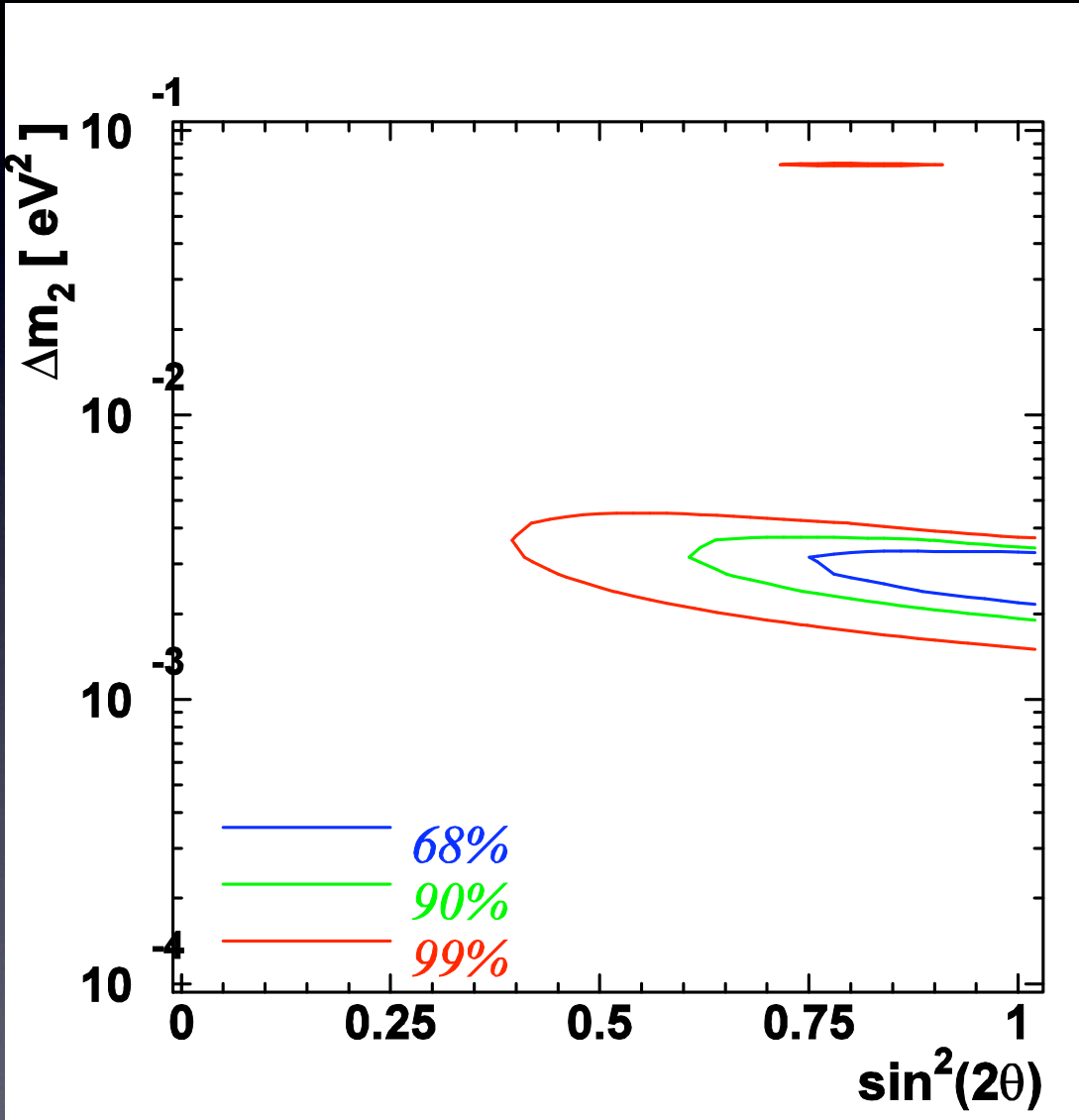
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158.4^{+9.4}_{-8.7} expected

Null oscillation excluded
at 4.4σ

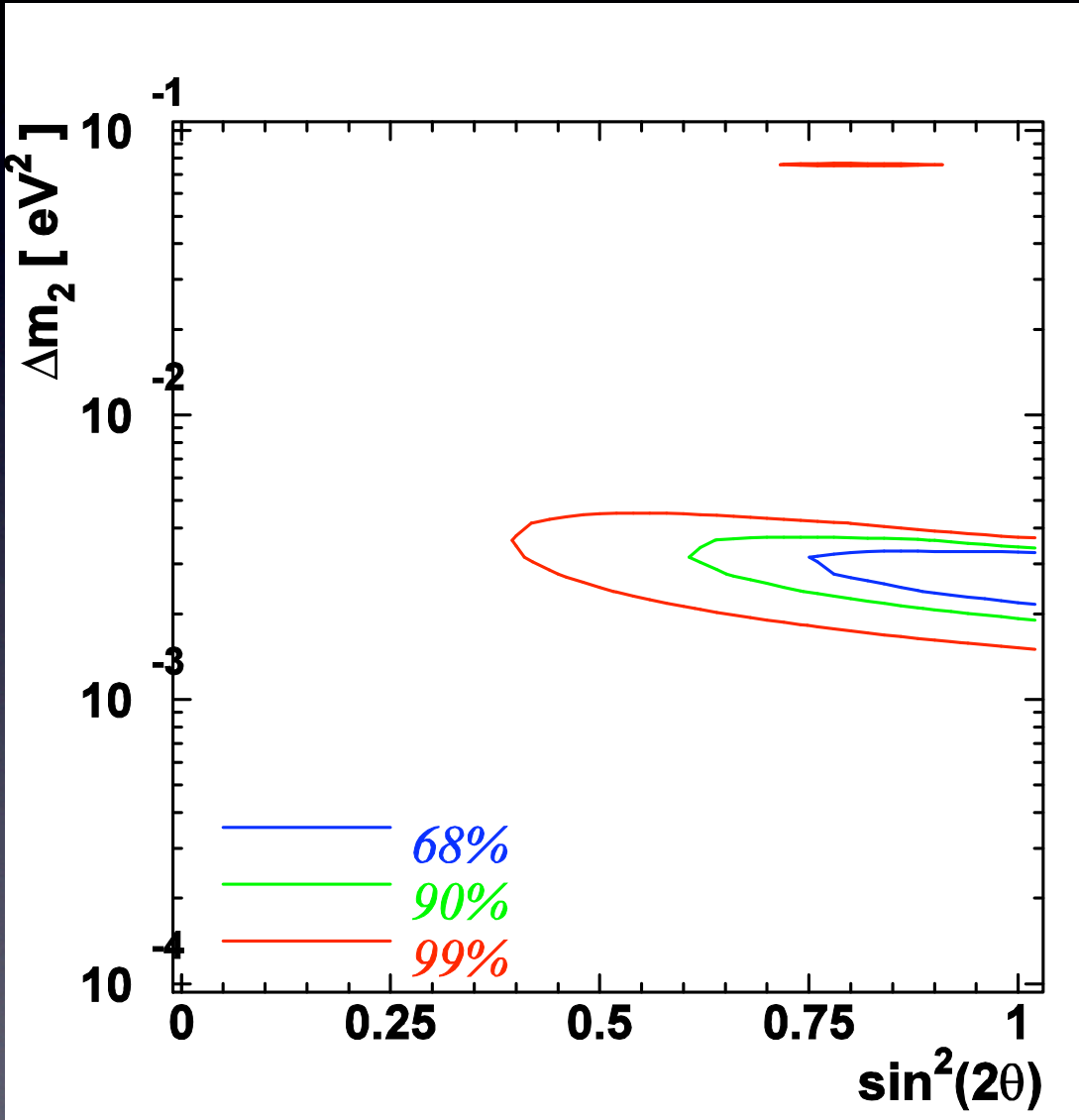


Oscillation parameters



- Best fit values:
 $\sin^2 2\theta = 1.0$
 $\Delta m^2 = 2.77 \times 10^{-3} \text{ eV}^2$
- $1.93 \leq \Delta m^2 \leq 3.48$
 $\times 10^{-3} \text{ eV}^2$
@ $\sin^2 2\theta = 1$ (90%CL)

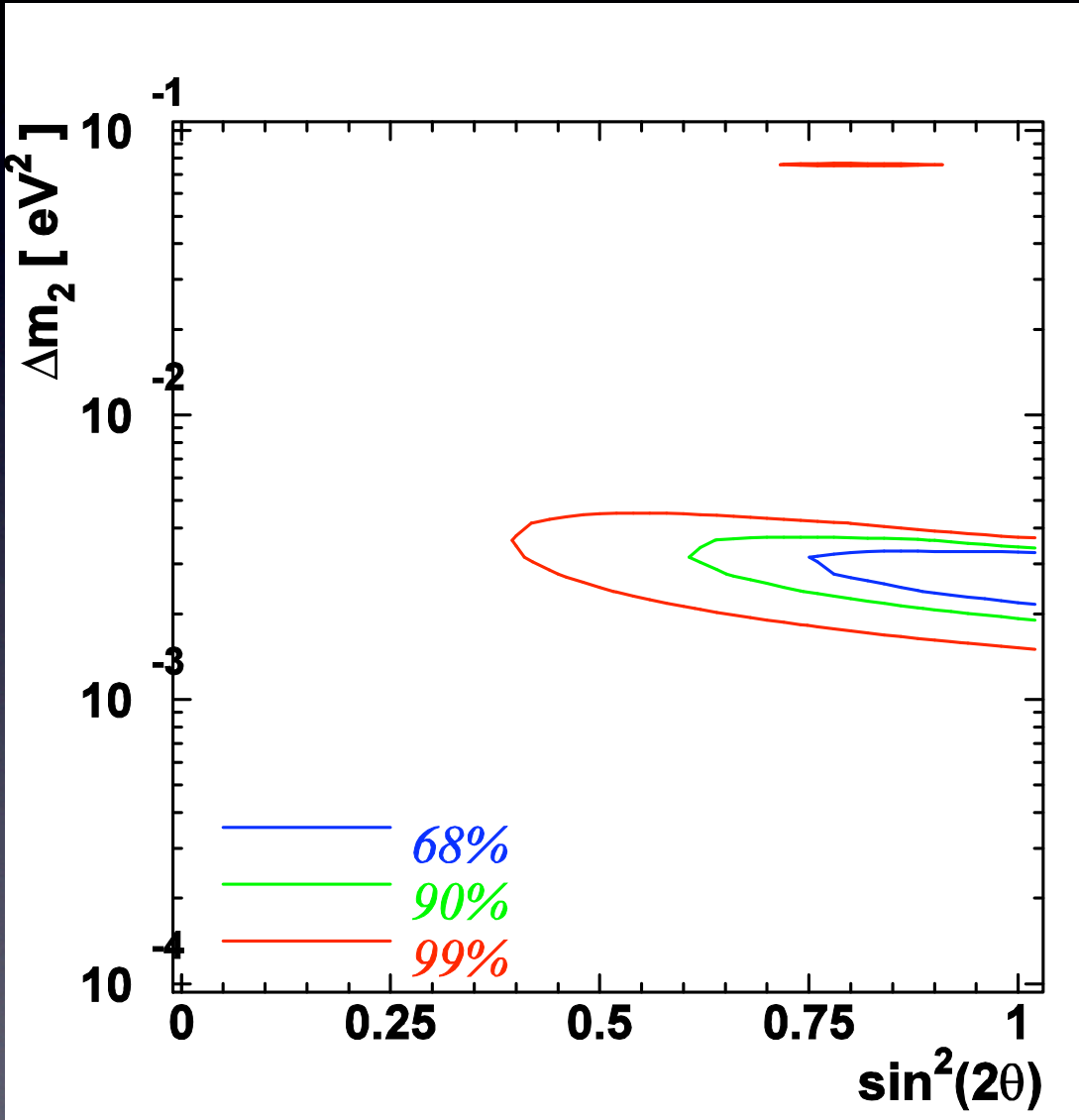
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**Confirmed Super-K
atmospheric ν result!**

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**Confirmed Super-K
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Established long-baseline
experiment!!!

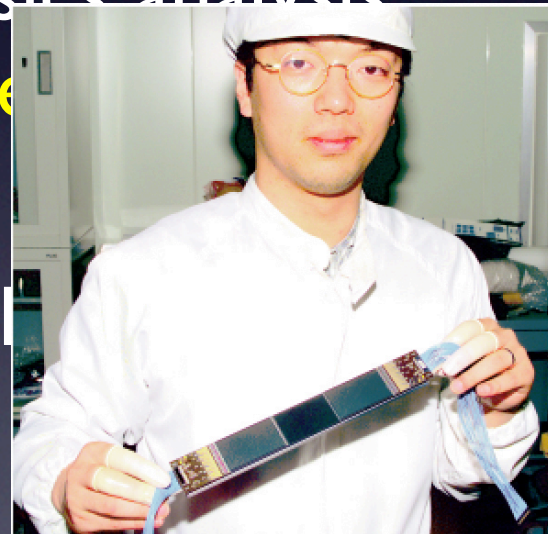
Future program

Past experiences

- Six years of experience with Belle **silicon system**
 - ✦ Both on **hardware** (ladder assembly, electronics commissioning, upgrade R&D) and **software** (alignment manager, calibration)
 - ✦ Complex and important physics analysis
Observation of time-dependent CP violation in B meson system (2001)
- Successful postdoctoral research in different field
 - ✦ **Convener of SciBar group** at K2K
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 - ✦ Development of **new photon sensor** for T2K ND

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 - ✦ **Leader of muon monitor & SVD ladder with MY (7 years ago...)**
 - ✦ Development of **new photon detector**

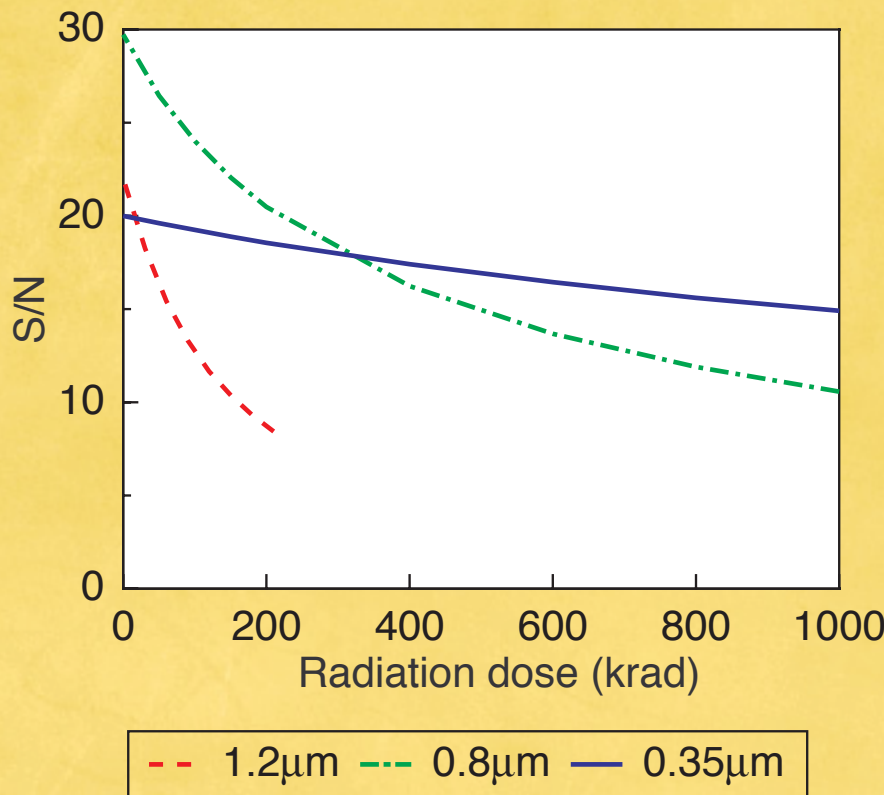


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Expected S/N of SVD
vs. radiation dose

important physics analysis
e-dependent **CP violation** in B
(I)

research in different field

group at K2K

monitor group at T2K

new photon sensor for T2K ND

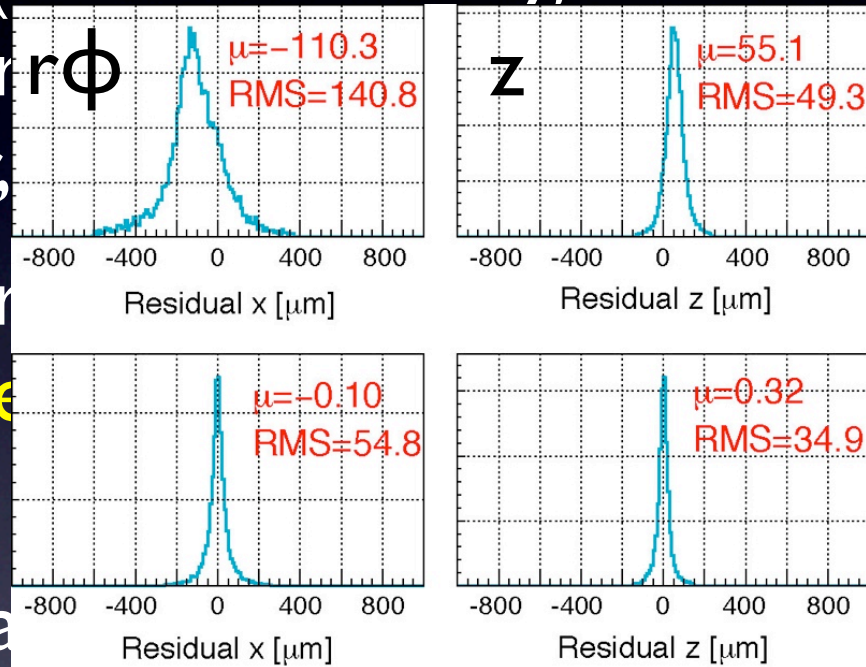
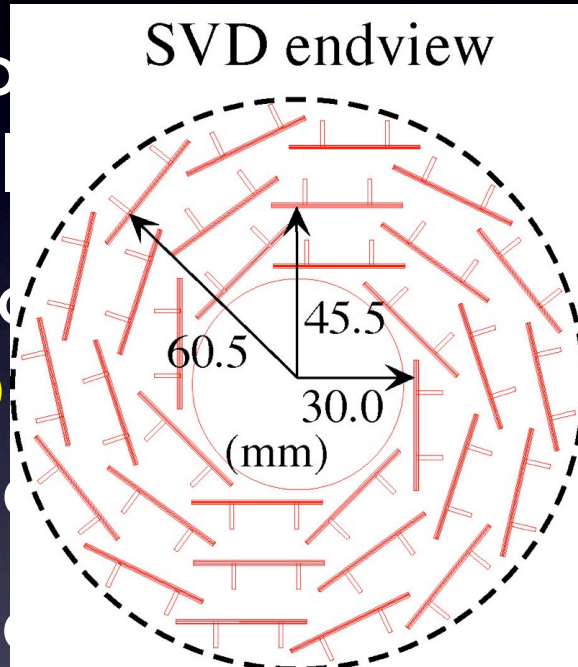
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Past experiences

- Six years of experience with Belle **silicon system**

- ✦ Both on **hardware** (ladder assembly, electronics



- Success

- ✦ Convener of SciB Residual before (top) and after (bot.) alignment
- ✦ Leader of muon monitor group at T2K

- ✦ Development of **new photon sensor** for T2K ND

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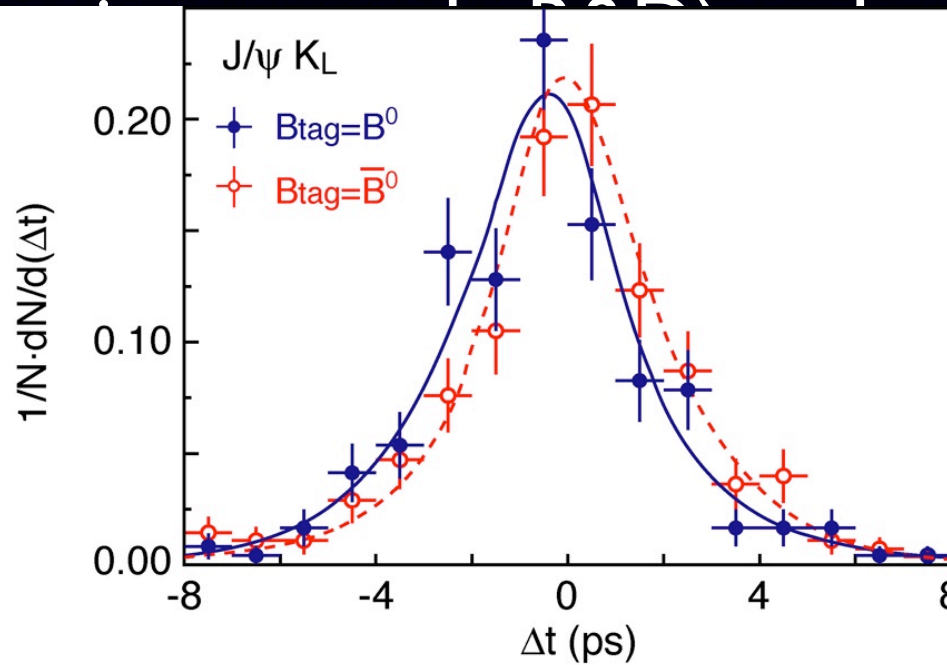
Past experiences

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- ✦ Both on **hardware** (ladder assembly, electronics commissioning) and **software** (alignment)

- ✦ Complex **Observation** of CP violation in B meson system

- Successful **Measurement** of $\sin 2\beta$ in $B \rightarrow J/\psi K_S$ mode



- ✦ **Convened** the **Time dependent asymmetry** workshop
- ✦ **Leader of** the **in $B \rightarrow J/\psi K_L$ mode** working group

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Past experiences

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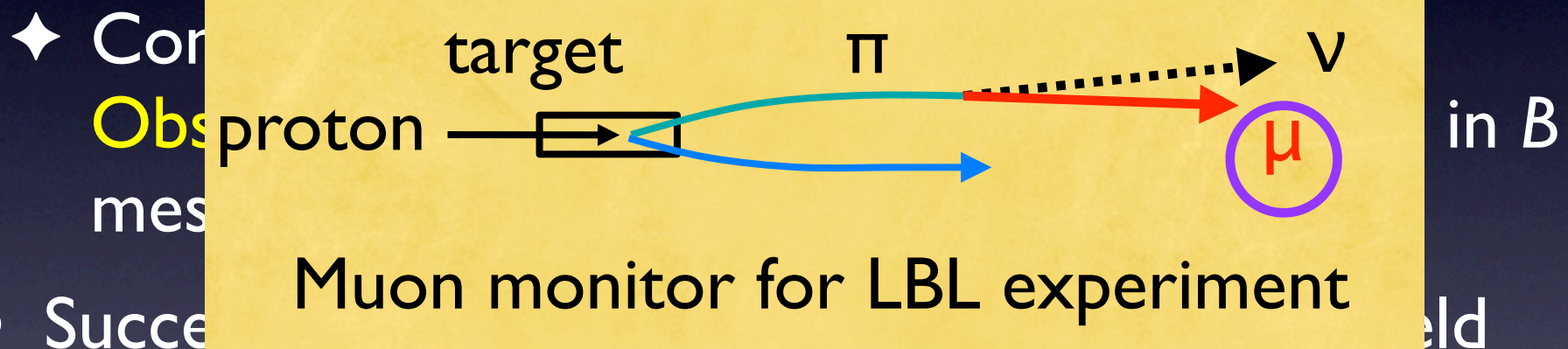
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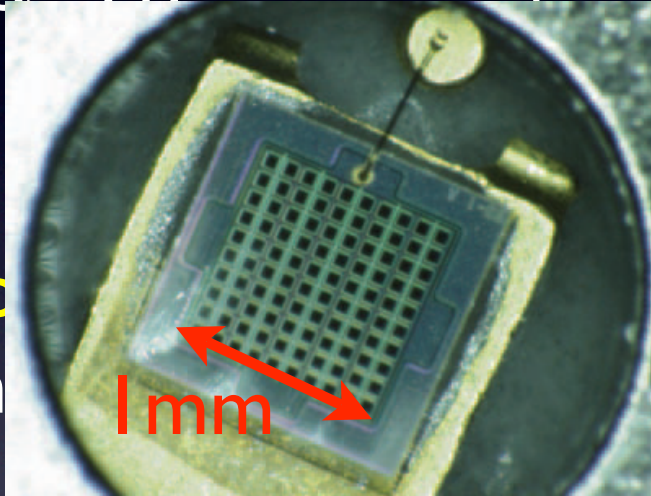
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Research interest

- My past research revealed **flavor structures** of quarks (Belle) and leptons (K2K)
- Next step is study of **Higgs sector**
 - ✦ Or, equivalent to Higgs for EWSB!
- **LHC** is coming to reality in $< \text{two years}$
 - ✦ FNAL's strong involvement in CMS
 - ✦ Excellent silicon detector facility/group
- Next-to-next step will be **Linear Collider**

Research plan

Research plan

- Commitment to CMS tracking system
 - ✦ Expertise and strong interest in silicon system, commissioning and startup of experiment

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 - Light SM Higgs / MSSM Higgs
 - New particle search
- Also interested in future semiconductor detector R&D
 - ✦ LHC upgrade and/or ILC

Questions in current particle physics (with accelerators)

(or, summary of this talk)

MY personal timeline

- Flavor structure and CPV of quarks past
- Neutrino properties present
- Origin of electroweak symmetry breaking
- “New” physics (SUSY? LED? anything else???)

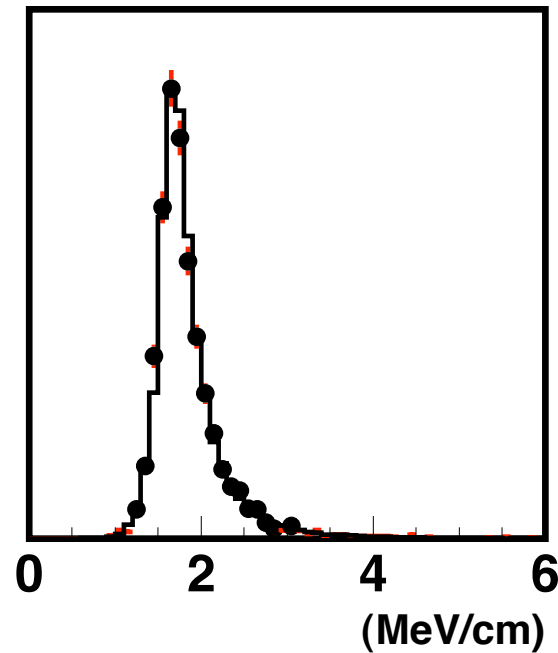
future !!



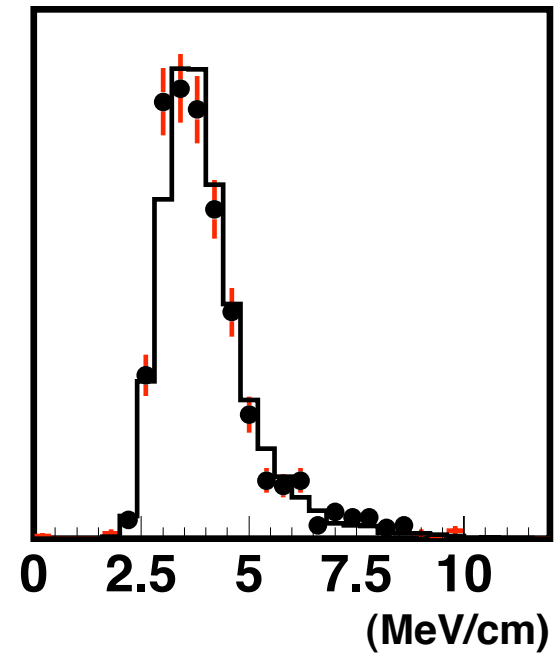
Thank you!

dE/dx calibration

Cosmics +
scintillator
quenching
(beam test)



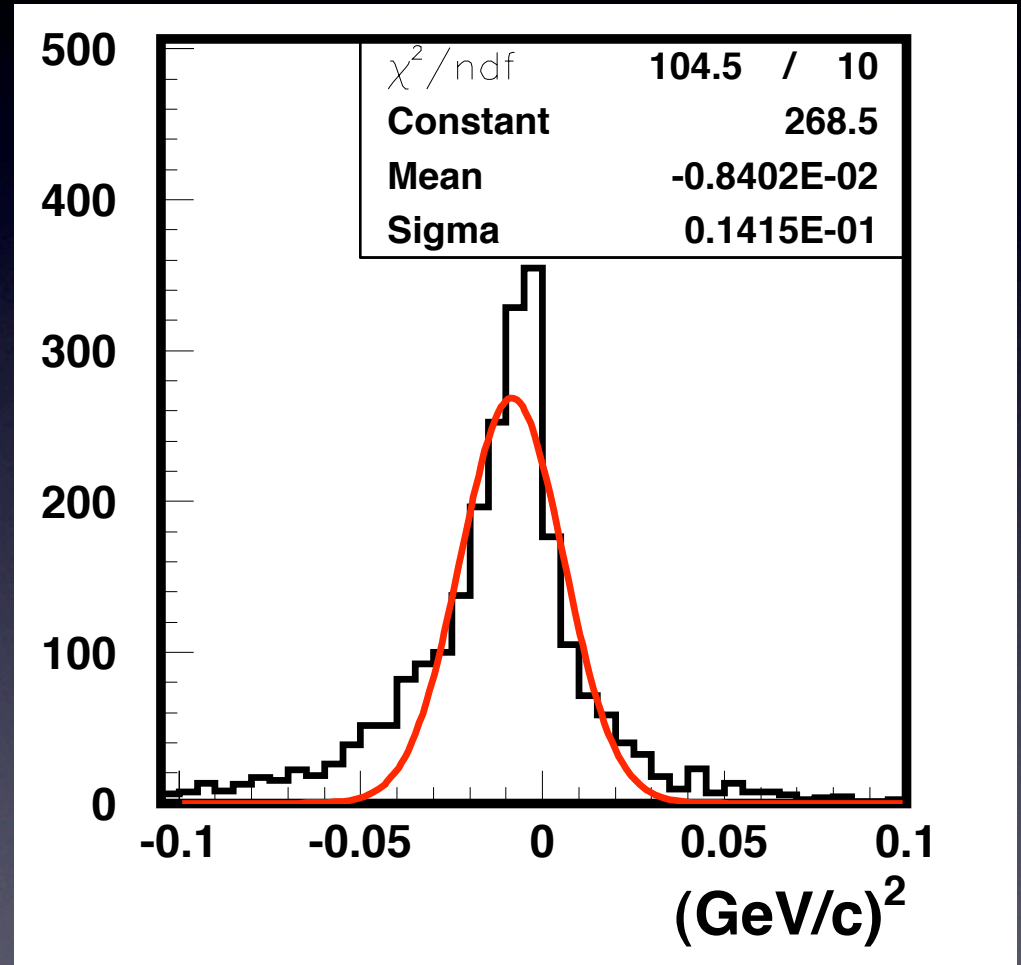
Muons



2nd tracks

q^2 reconstruction

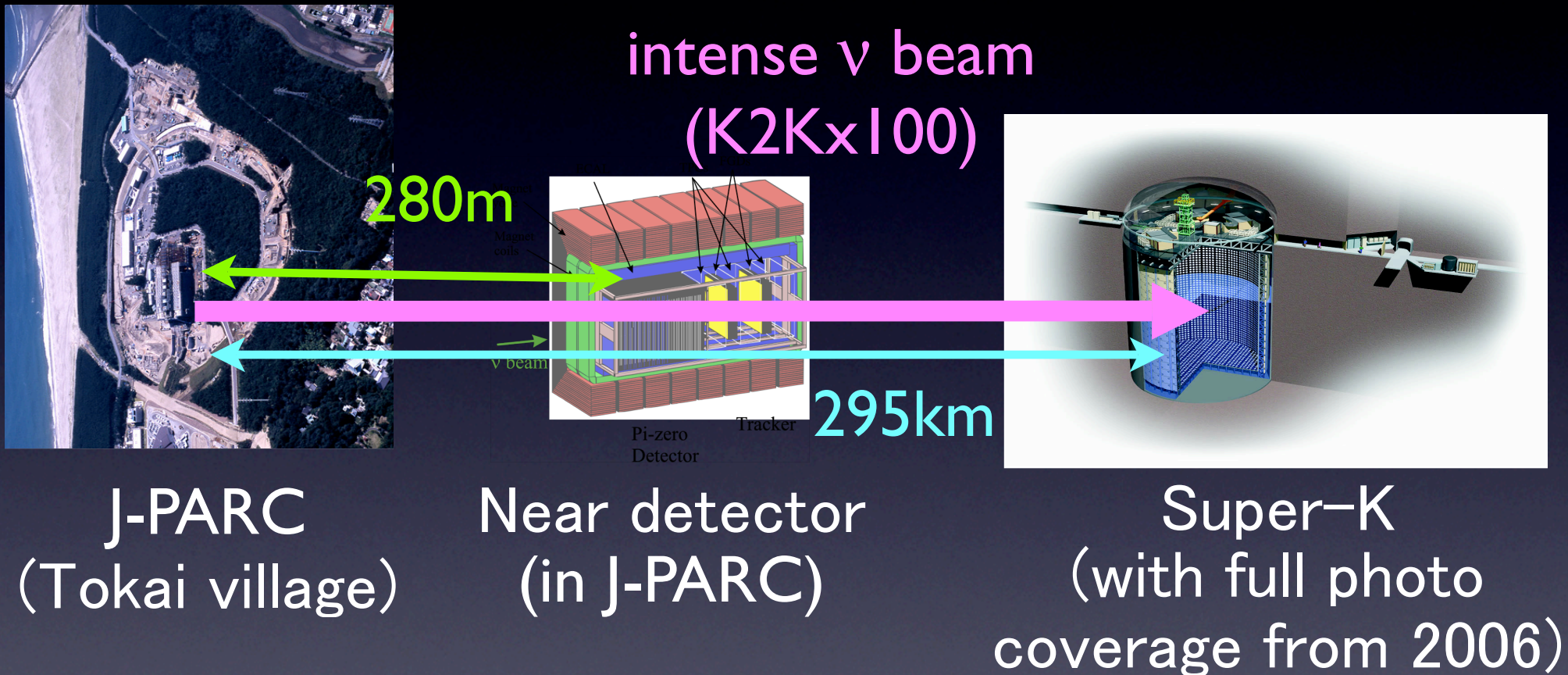
- Although QE is assumed in q^2 calculation, coherent pion events are nicely reconstructed as low- q^2 due to small scattering angle



R&D for T2K

Development of a new photo detector
–Multi-Pixel Photon Counter (MPPC)–

T2K experiment



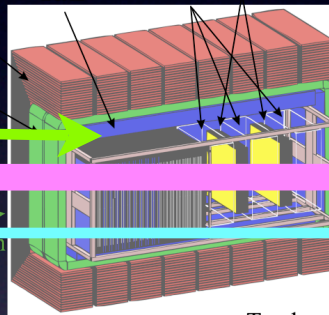
- Beamline construction from 2004
- Experiment will start from 2009

T2K experiment



J-PARC
(Tokai village)

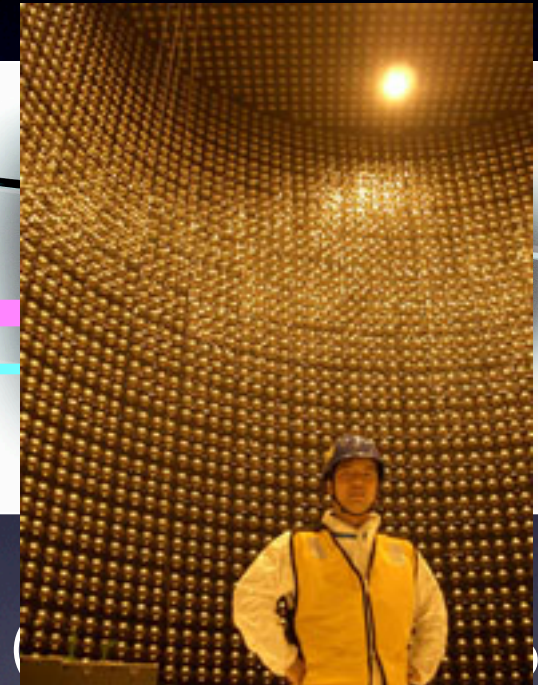
280m



Near detector
(in J-PARC)

295km

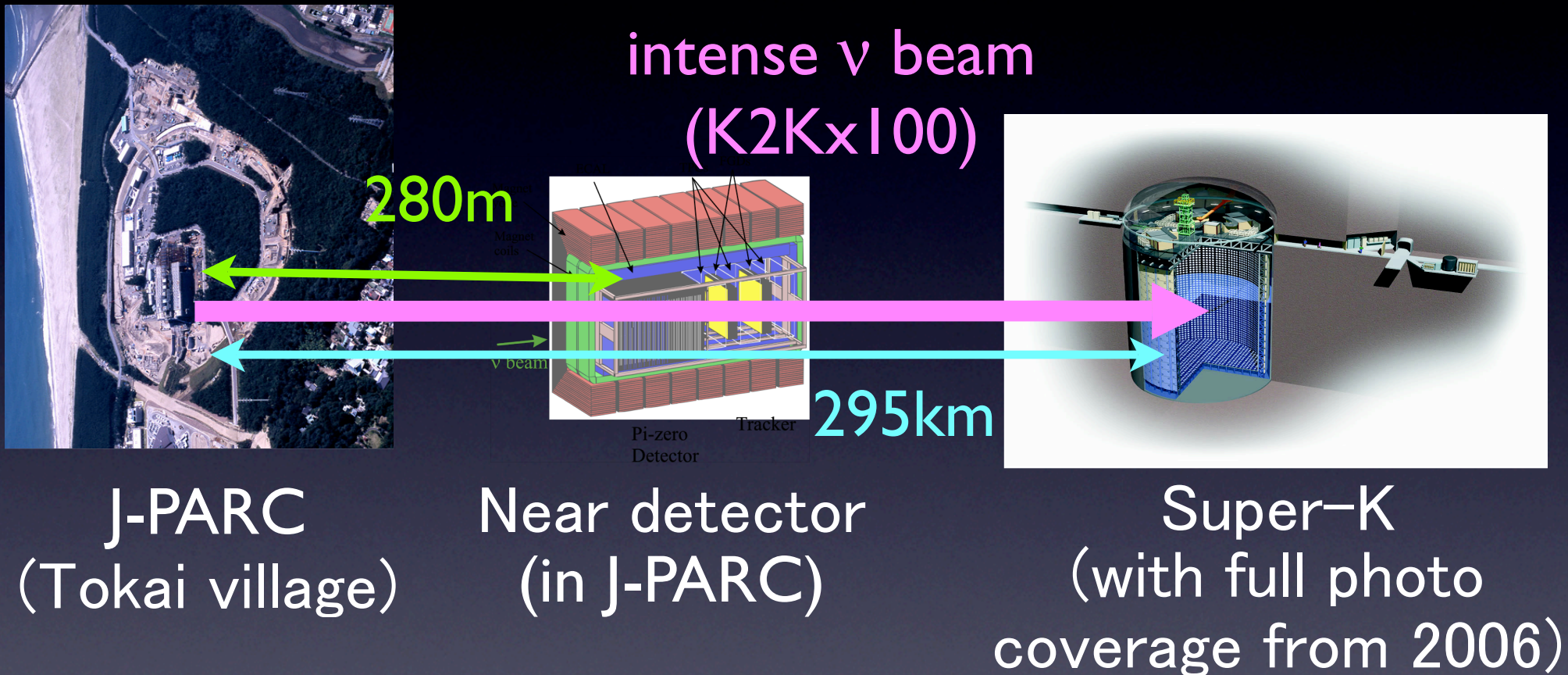
Feb 17, 2006



coverage from 2006)

- Beamline construction from 2004
- Experiment will start from 2009

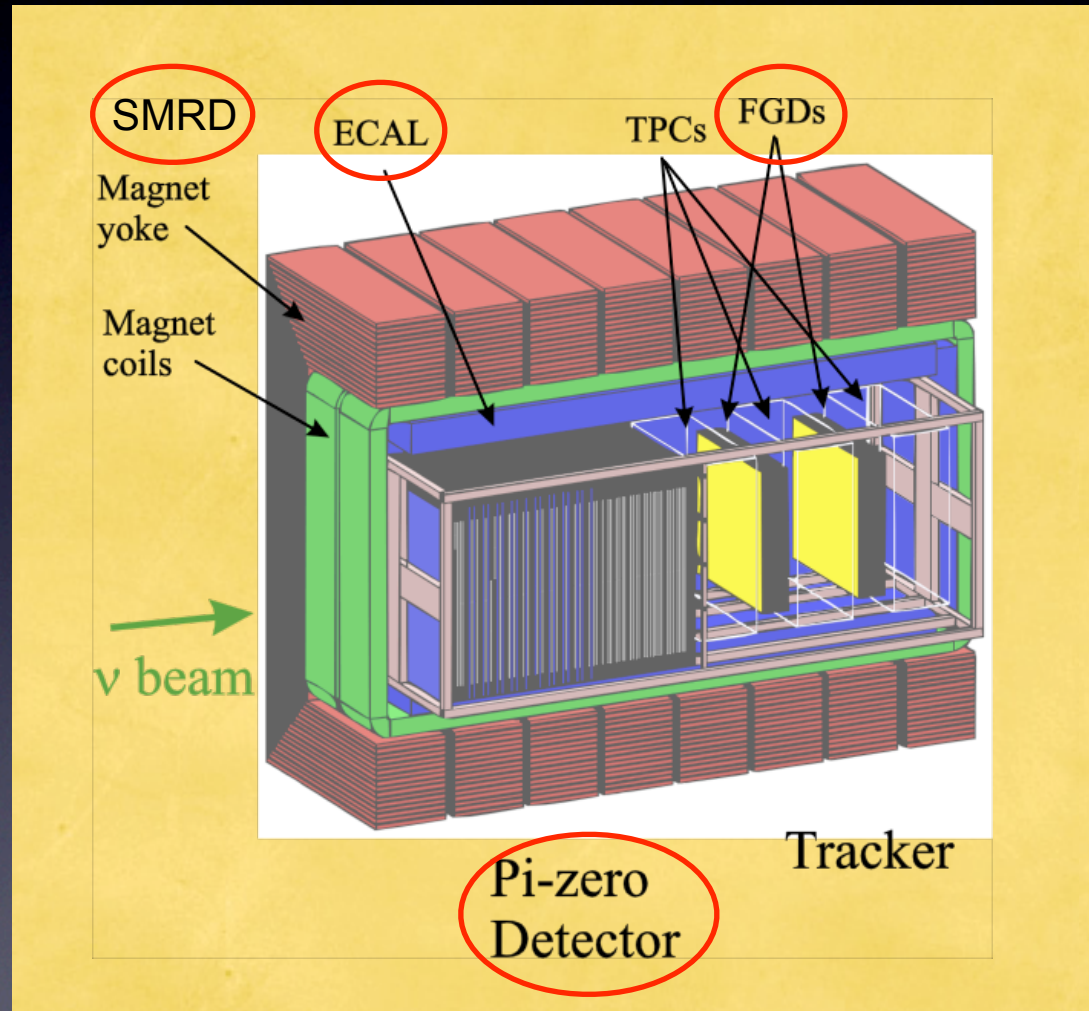
T2K experiment



- Beamline construction from 2004
- Experiment will start from 2009

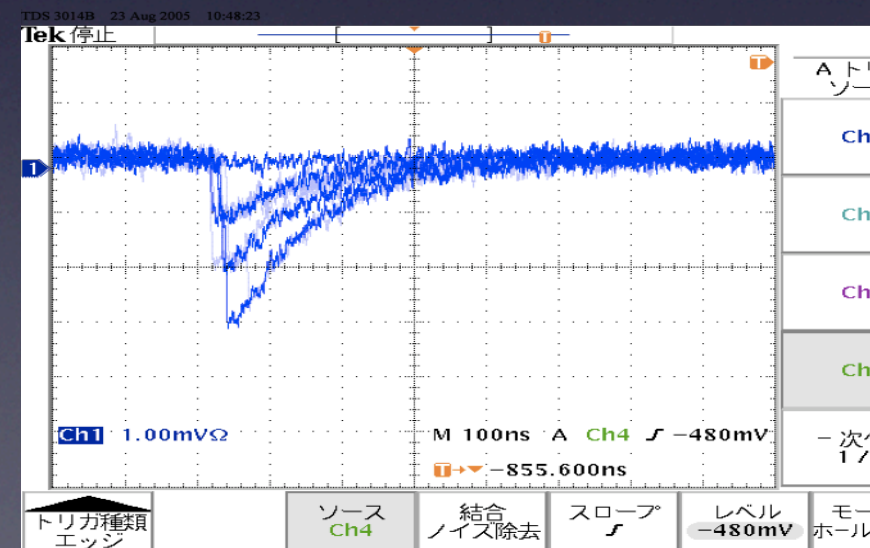
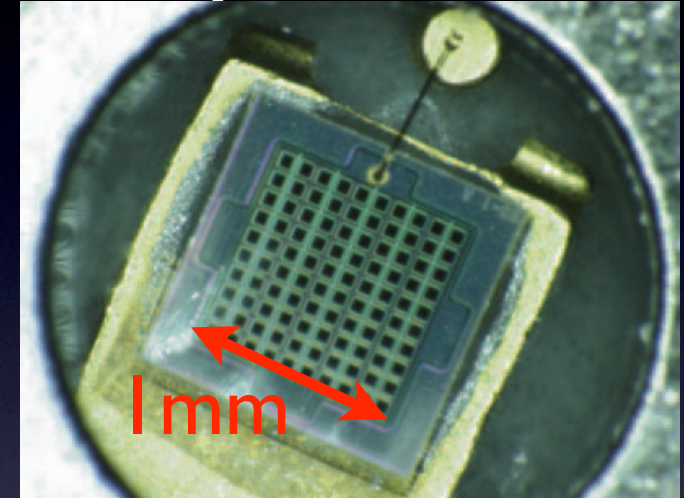
Near detector system

- Inside UAI magnet
 - ✦ 0.2T B-field
- Extruded scintillator + WLS fiber readout in many sub-detectors
- Need novel photo detector



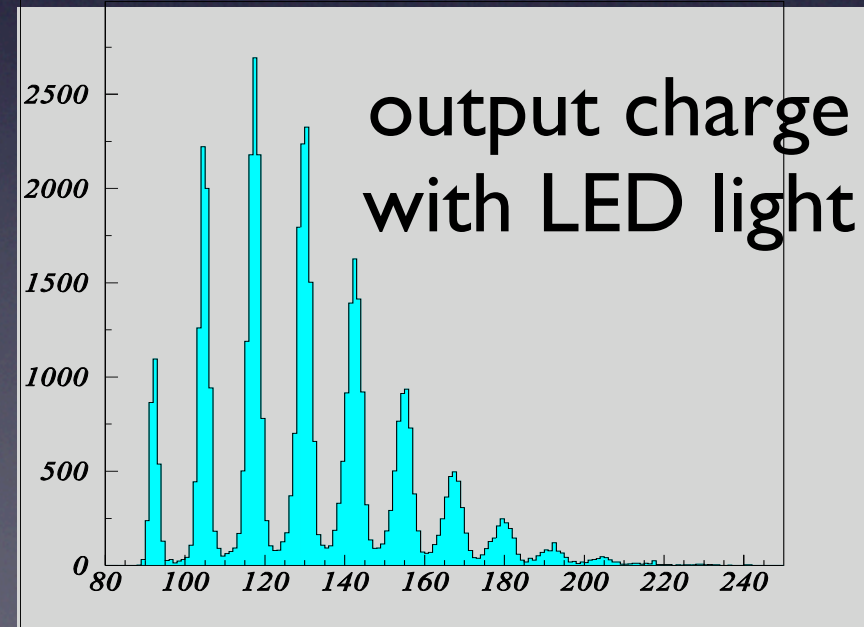
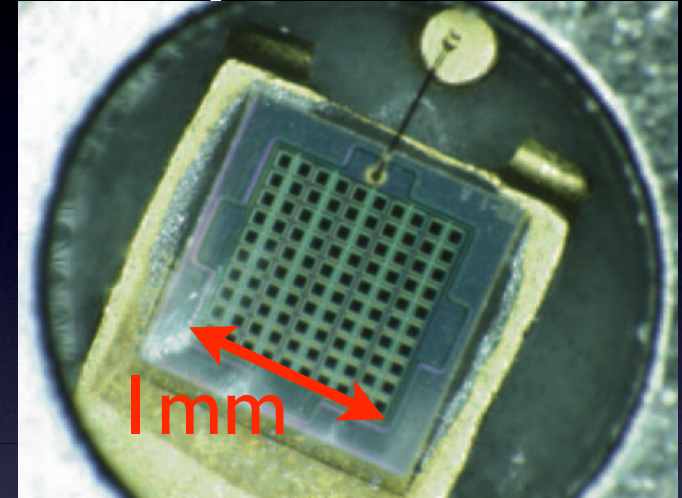
Multi-Pixel Photon Counter (MPPC) a.k.a. “SiPM”

- 100-1000 APD pixels in $\sim 1 \times 1 \text{ mm}^2$ area
- Each pixel works in Geiger mode
 - ✦ Gain $\sim 10^6$
 - ✦ Output charge proportional to number of “fired” pixel
- Excellent photon counting capability
- Operational in magnetic field



Multi-Pixel Photon Counter (MPPC) a.k.a. “SiPM”

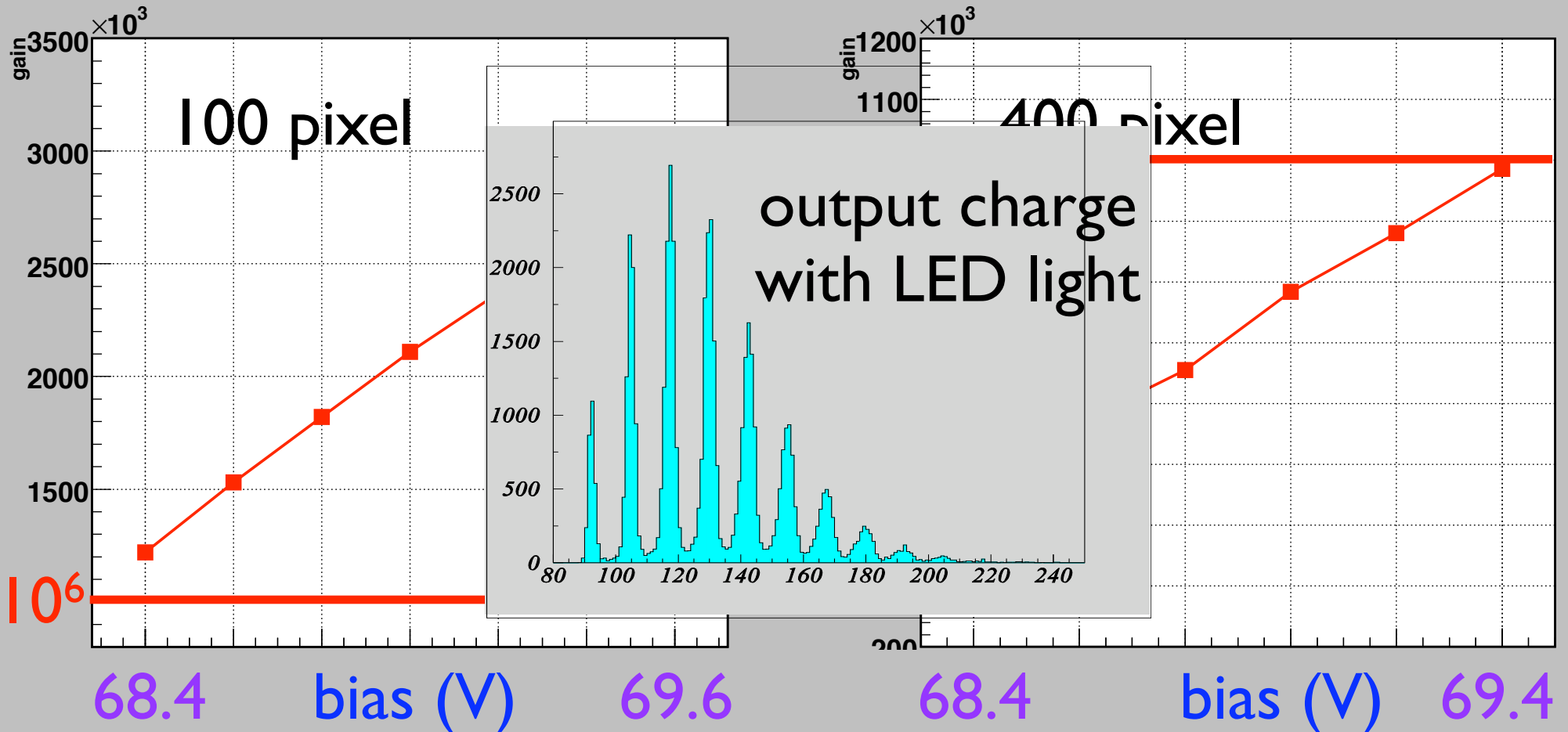
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- Each pixel works in Geiger mode
 - ✦ Gain $\sim 10^6$
 - ✦ Output charge proportional to number of “fired” pixel
- Excellent photon counting capability
- Operational in magnetic field



MPPC R&D

- Cooperative development with Hamamatsu Photonics from late 2004
- Chosen as a **baseline option** for T2K near detectors (Together with Russian “SiPM”)
- Three iterations in ~a year
 - ✦ Steady improvement in characteristics
 - ✦ Better understanding of device
- Test results of latest samples (100/400 pix, Jan. 2006) presented here

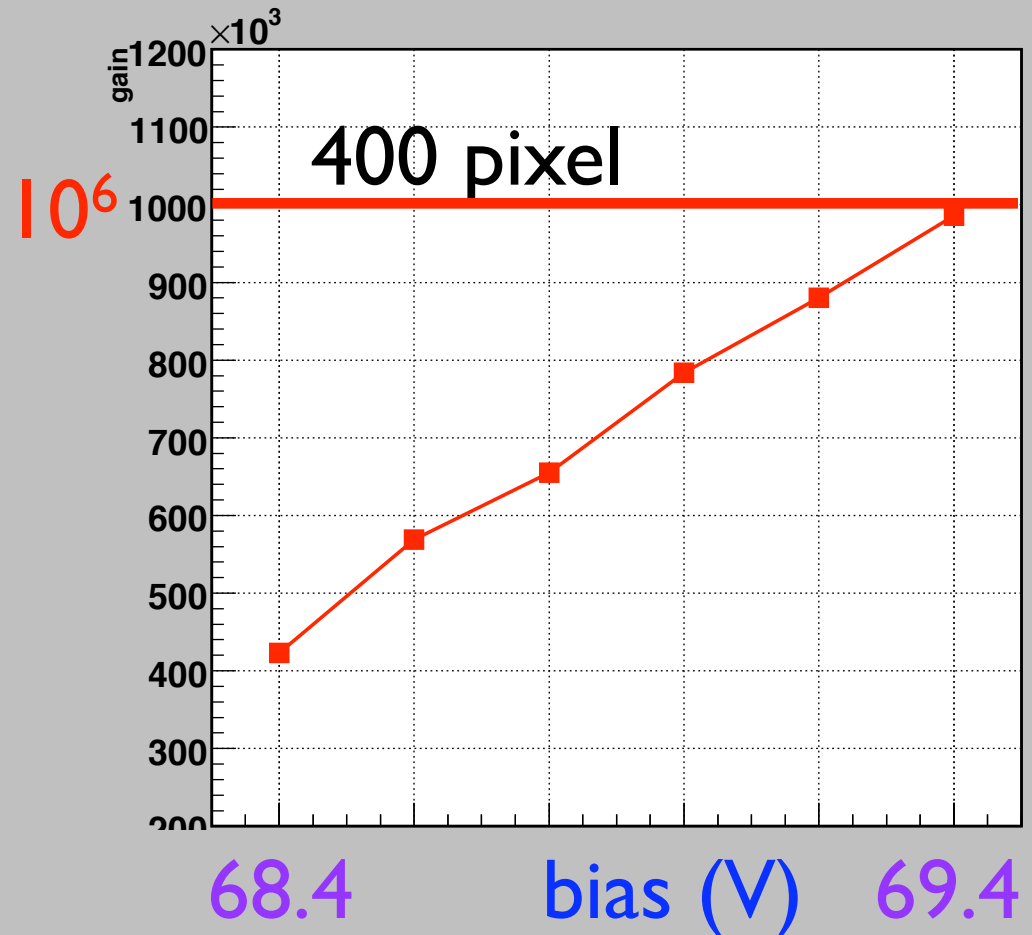
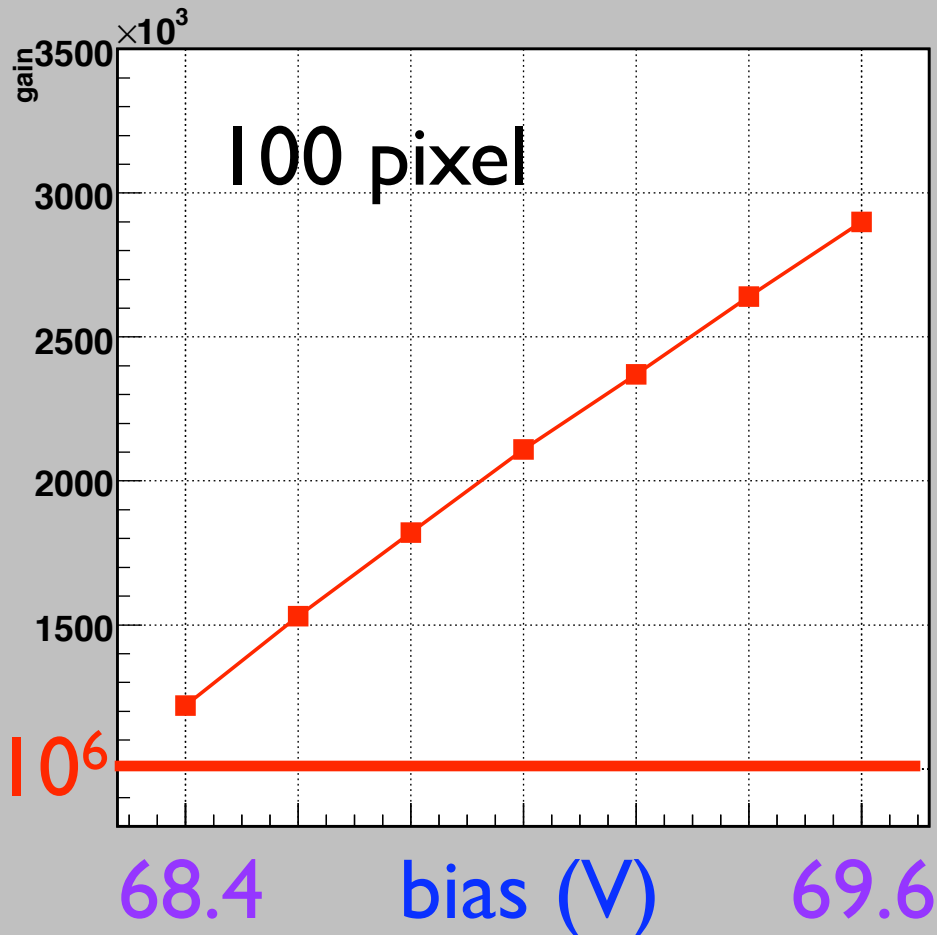
Gain



Slope depends on capacitance (=pixel size)

All measurements at 20°C

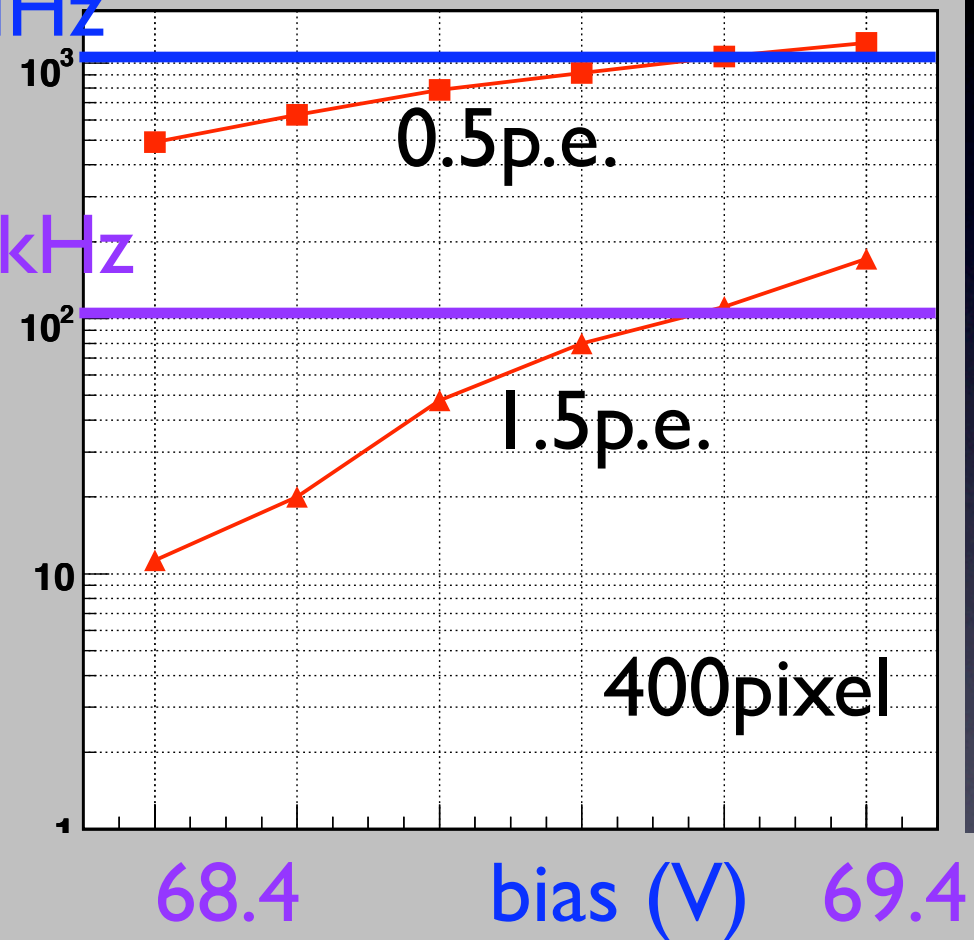
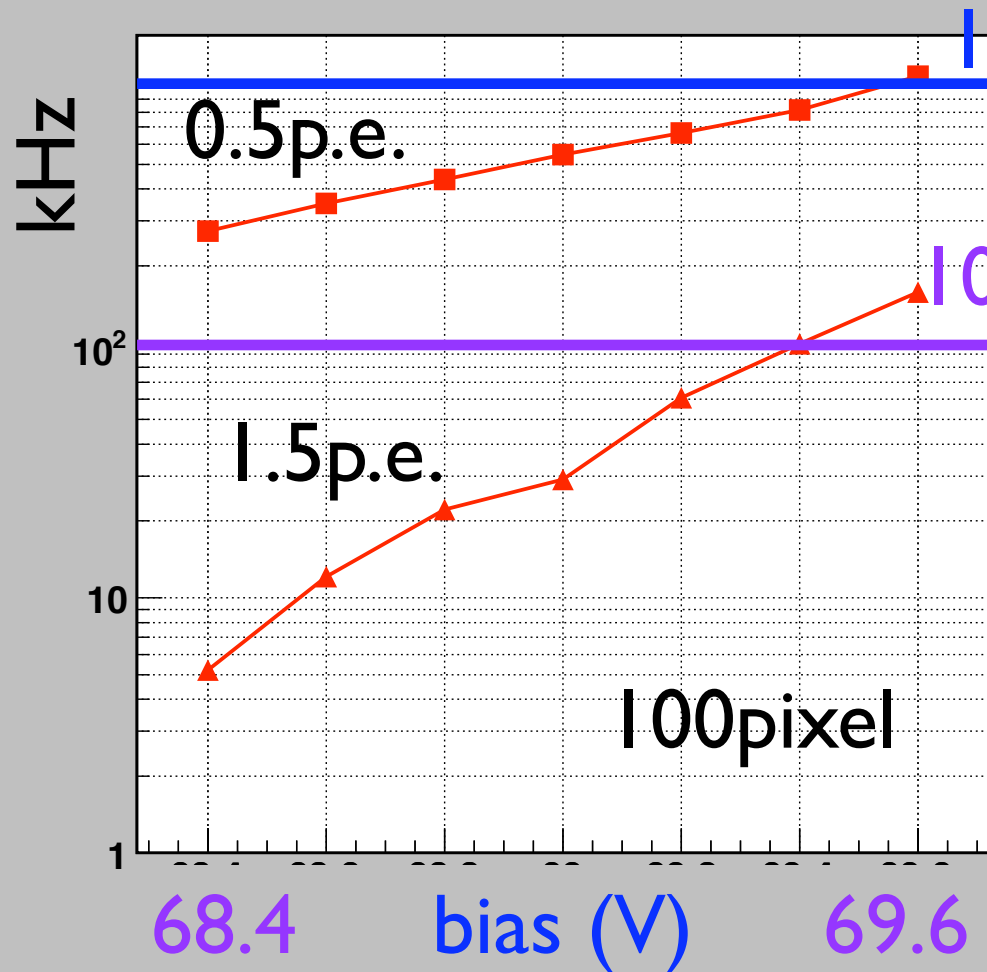
Gain



Slope depends on capacitance (=pixel size)

All measurements at 20°C

Noise rate



Photon detection efficiency

- Efficiency = (Geometrical) \times (Quantum eff.)
 \times (Geiger mode probability)
- Measured using PMT as reference (QE 15-20%)



PMT (cathode limited to
 $1 \times 1 \text{ mm}^2$ by black sheet)

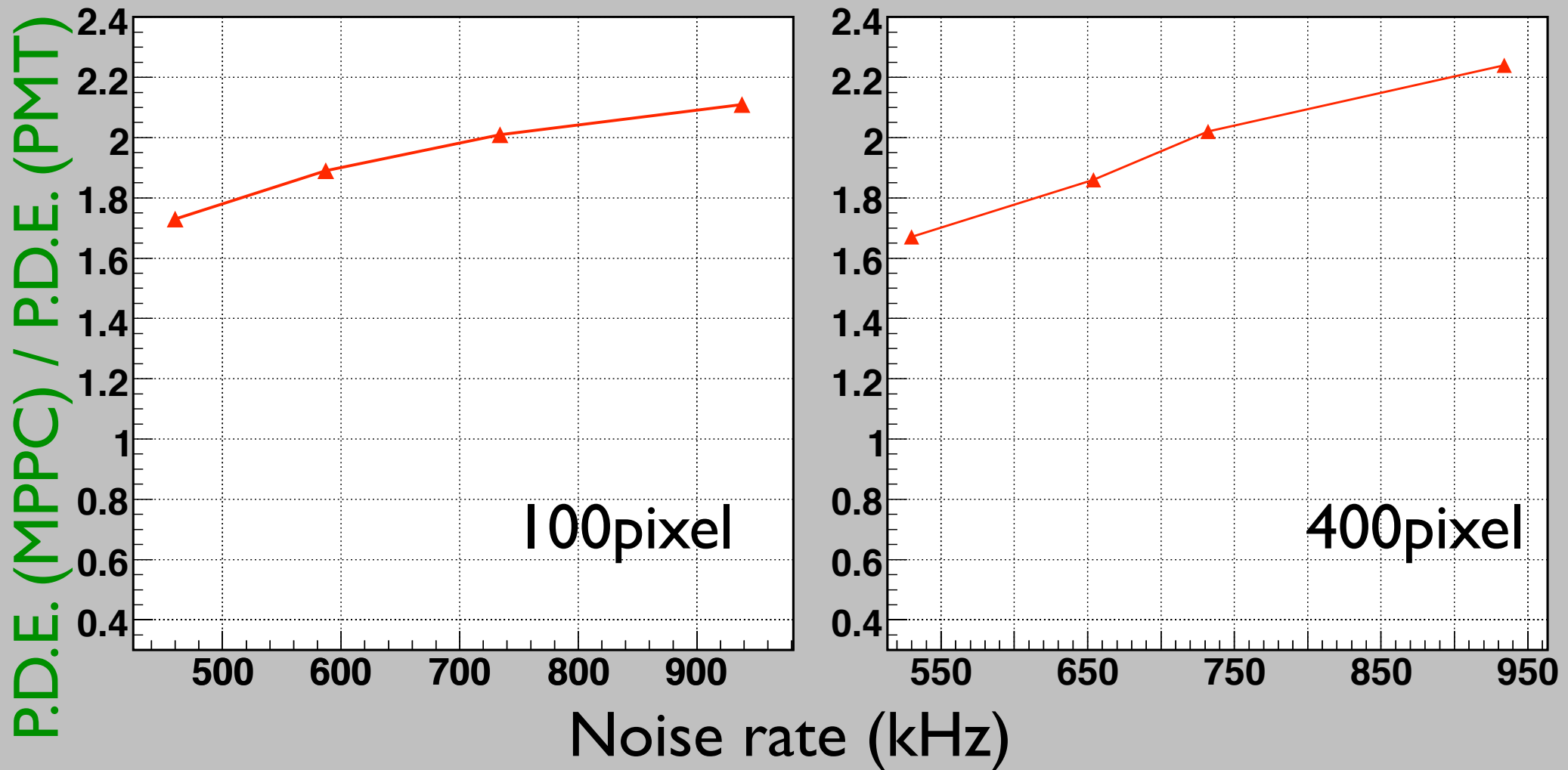


MPPC

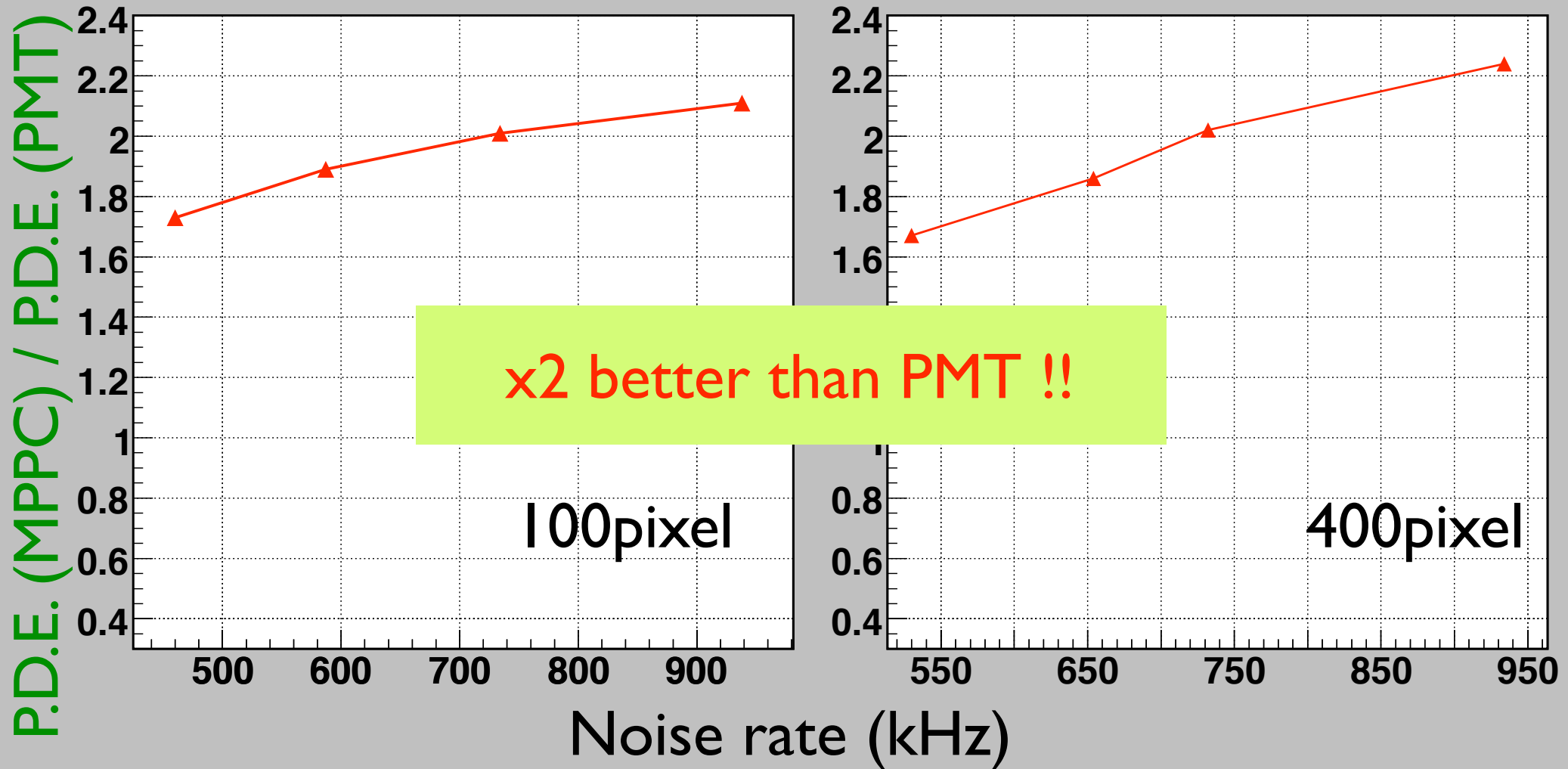


Uniform light from WLS fiber

Photon detection efficiency

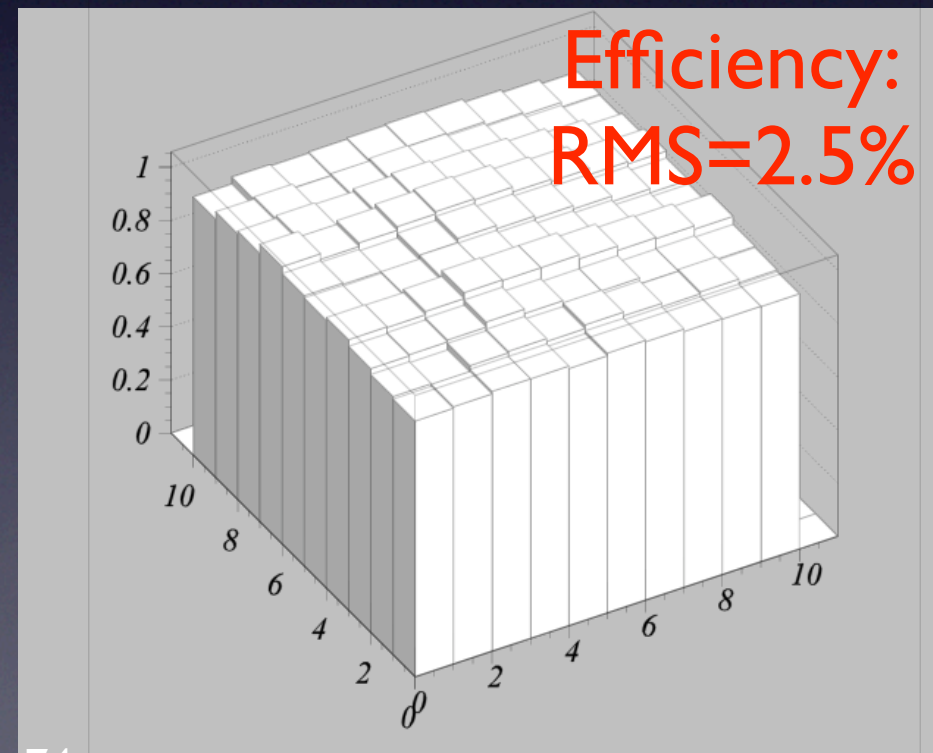
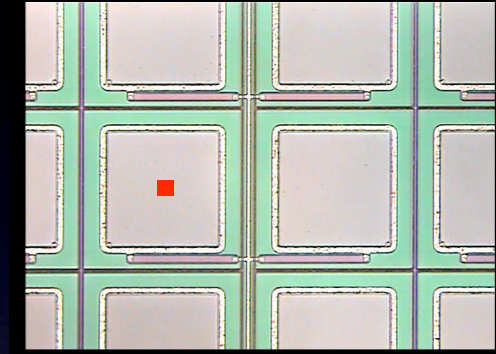


Photon detection efficiency



Response with spot laser

- Inject laser light to center of each pixel
 - ✦ spot size $\sim 10\mu\text{m}$
 - ✦ 100 pixel sample (pixel size $100\mu\text{m}$)
- Uniform response of all 100 pixels
 - ✦ Gain: $\text{RMS}=3.6\%$



MPPC summary and plan

- Basic performance of MPPC **nearly satisfies requirement of T2K**
 - ✦ Experiment starts in 2009, construction in 2007/8
- Development continues this year
 - ✦ **Semi-mass production**
 - ✦ **Packaging** to fit fiber readout
 - ✦ Further improvement/test of performance
- LC calorimeter group also participates in R&D
 - ✦ Needs >1000 pixel device for linearity